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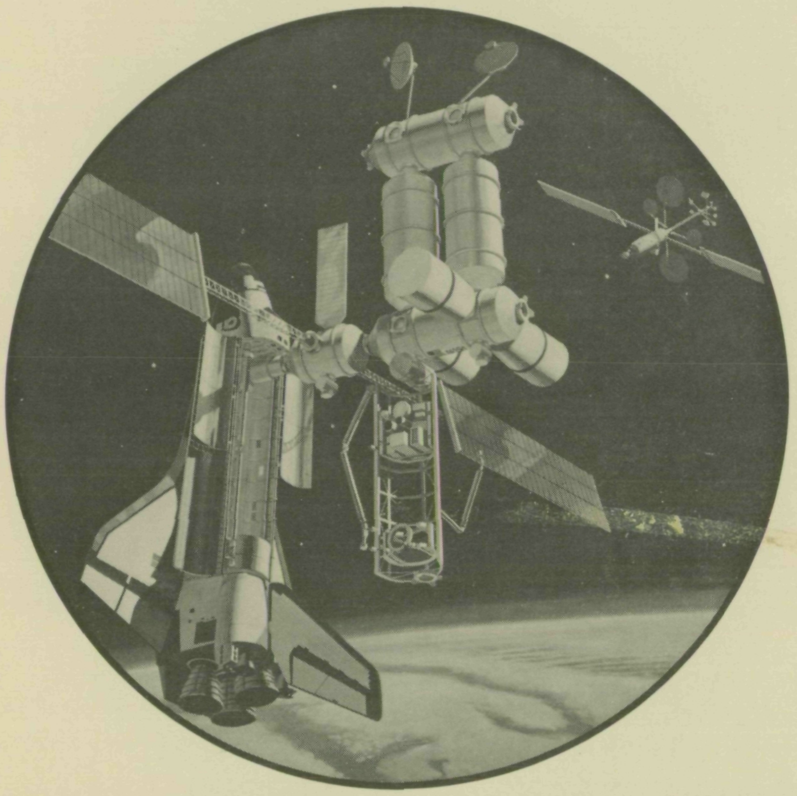
SPACE STATION NEEDS, ATTRIBUTES, AND ARCHITECTURAL OPTIONS STUDY

Volume I



MISSIONS AND REQUIREMENTS

APRIL 22, 1983

CONTRACT NASW 3683

Rockwell International

Shuttle Integration &
Satellite Systems Division
Rockwell International Corporation
12214 Lakewood Boulevard
Downey, California 90241

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FOREWORD

The Space Station Needs, Attributes, and Architectural Options Study contract (NASW 3683) was conducted by the Rockwell Shuttle Integration and Satellite Systems Division for NASA.

The final report summarizes the results of this study in five volumes, which are:

- Final Executive Summary Report
- Missions and Requirements
- Program Options, Architecture, and Technology
- Cost and Benefits
- DOD Task

Any questions regarding this final report should be directed to G.M. Hanley, study manager, at (213) 922-0215.

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CONTENTS

ILLUSTRATIONS

TABLES

1.0 INTRODUCTION

This report summarizes the main results of the mission model development effort and the subsequent time-phased Space Station requirements derived therefrom. The mission models presented here are the result of several cycles of refinement, beginning with Mission Scenario 4 at the start of the study, continuing with Mission Scenario 5 at the study mid-term, and finishing with Mission Scenario 6, which is presented here. The main points of refinement have been to incorporate updates on current user thinking and mission plans, as well as new and improved ways to achieve their objectives by using Space-Station-based services. Through these factors we have produced a representative and realistic mission model validated by user acknowledgment and meeting the balanced objectives and needs of the U.S. Space program through the year 2000.

Mission model development efforts have included the support of six subcontractors and numerous contacts within the various Science and Applications disciplines and planning groups. The six subcontractors are Mr. Walter Morgan, support to the commercial communications model development; GTI, MRA, Dr. M. Bier (University of Arizona), support to the commercial space processing model develoVment; and Dr. Jill Fabricant (University of Texas) and the Bionetics Corporation, support to the Life Sciences model development.

Our final mission scenario comprises two basic models: Scenario 6, which reflects achievement of user objectives with the maximum practical use of a Space Station, and Scenario 6A, which reflects the expected changes to the mission model due to the absence of a Space Station. Scenario 6A provides the mission model differences needed to properly assess Space Station benefits as well as other points of programmatic comparison. To aid in assessing station requirements and architectural sensitivities to traffic variations, low, medium, and high models were constructed for Scenario 6. Thus, Mission Scenario 6 is the basis for the time-phased station requirements.

The time-phased system requirements summarized in this report have been developed for the Mission Scenario 6 mission model for the baseline-recommended Space Station program option. This baseline is the option three program, which utilizes an initial four-person station located in low earth orbit at 28.5° inclination, growing to a full-capability eight-person station. For this study the requirements were generated for the following specific resource areas: payload mass processed, propellants, crew hours, power, data processing, and storage volume interfaces. These requirements were developed from the mission model for the user mission requirements set, and then the station facility requirements were determined through system and subsystem sizing in the supporting studies in order to obtain the total integrated resource requirements for user and facility services. The missions routed through the station, from the total model were the complete low-inclination mission set and the high-energy orbit medium inclination mission set. The resulting resource requirements are presented for the low, medium, and high mission model levels.

The main technical content of this document is presented in Sections 2 through 4. Section 2 covers the overall mission model development and shows a summary of the models for Scenarios 6 and 6A. These are followed by model construction and mission definition details in Section 3 for each of the individual user areas. Section 4 presents the time-phased requirements development efforts.

2.0 MISSION MODEL SUMMARY

This section gives a top-level summary of the mission models for Scenarios 6 and 6A, with and without a Space Station, respectively. The models are structured in terms of missions per year by user area and for Scenario 6 include low, medium, and high levels of mission activity. Emphasis is on the medium model which is premised on a modestly vigorous national space program and its likely positive influences on commercial programs. Thus, the medium model is our best estimate of the expected levels of mission activity and the types of missions likely to fly through the year 2000 time period. It reflects the existence of a manned Space Station and other complementary STS elements, including a space-based orbital transfer vehicle (OTV), a station-based teleoperator maneuvering system (TMS), a GEO-based TMS, and Shuttle/station-tended platforms.

The low model presumes lower funding is available for both government and private space endeavors because of pressures from other priority programs and continued sluggish patterns of world economic growth. It reflects budget constraints in government programs, pessimistic market forecasts for commercial activities, and essentially continues the current DOD space functions with no new types of DOD missions introduced. It is unlikely that world events could produce a more severe downturn in space activity. Thus, the low model represents a very high probability of occurrence almost certain to be achieved, not necessarily on a mission by mission basis, but as a representative total.

The high model presumes a vigorous space program driven by a return to a strong world economy, particularly in the high technology sector. It reflects modest increases in some of the NASA programs (planetary, life sciences, etc.), significant increases in commercial programs associated with optimistic market forecasts, and significant increases in DOD programs associated with the addition of survivability and strategic/tactical missions over those in the medium model.

All of these models were developed in close coordination with the users and reflect the maximum practical use of the Space Station and station-based services. Table 2-1 summarizes the number of missions by user area through the year 2000 for the medium model. Bottom line totals for the low and high models are also shown for comparison. These mission totals include deliveries, servicing missions, retrievals and sortie operations. Each time a user payload (or major payload/mission element) is transported, handled and/or processed by an STS element it is counted as a mission. For example, placing a materials processing free flyer into orbit initially is counted as a delivery mission. In the case of resupplying the free flyer (exchange of finished product for new raw material) it is counted as a servicing mission. Even though the factory resupply package is delivered first to the station by the Shuttle and then carried to the free flyer via a station-based TMS, the entire mission is counted as one TMS servicing mission. In essence, the mission count reflects the number of mass elements contained in the model, not the number of mission

Table 2-1. Mission Model Summary for Scenario 6

	MEDIUM MODEL										
USER AREA	YEAR										TOTAL
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
NASA SCIENCE & APPLICATIONS	6	14	11	18	17	15	17	15	14	16	143
GOVERNMENT ENVIRONMENTAL	1	1	1	1	1	1	1	1	1	1	10
COMMERCIAL RESOURCE OBS.	1	2	0	1	1	2	2	1	1	0	11
COMMERCIAL SPACE PROCESSING	29	29	29	30	37	35	41	49	56	72	407
COMMERCIAL COMMUNICATIONS	11	21	17	15	16	21	19	11	10	12	153
NATIONAL SECURITY	21	20	24	25	21	22	27	21	22	24	227
NASA TECHNOLOGY DEVELOPMENT	1	2	2	3	3	0	3	2	1	2	19
GEO SERVICING	0	0	0	0	1	2	1	3	2	2	11
MEDIUM MODEL TOTAL	70	89	84	93	97	98	111	103	107	129	981
LOW MODEL TOTAL	46	58	55	69	64	73	82	81	92	111	731
HIGH MODEL TOTAL	88	108	109	123	117	137	148	139	148	168	1285

steps involved in the disposition of these mass elements. A mission is counted as a retrieval mission when a spacecraft or satellite is returned to the ground (not to the Space Station) for refurbishing or major rework. If it is returned to the Space Station for rework it is counted as a servicing mission. Sortie missions conform to the historical definition; i.e., a payload carried to orbit and back in the orbiter and performing mission operations from the orbiter bay is a sortie flight. Other important nomenclature and key terminology used in this report are defined in Figure 2-1.

Tables 2-2 through 2-4 show the medium mission model grouped by distination region ranging from low inclination-low altitude to high inclination-low altitude. Numbers of payloads by user area and totals by year are shown.

To aid in establishing Space Station benefits and for additional programmatic comparisons, a medium model was established for Mission Scenario 6A, the case without a Space Station. This model is summarized in Table 2-5. It reflects changes from the model in Scenario 6 resulting from different ways of doing some of the missions without a Space Station. Significant reductions are shown in most user areas (except DOD). Constrained research and limited productivity is predicted for space processing, life sciences would be reduced to sorties, low-earth-orbit (LEO) on-orbit servicing missions would be reduced in number, geosynchronous-earth-orbit (GEO) servicing and space-based OTV's would be deleted, and technology development missions would be refocused to include station-related technologies which would likely occur to support a Space Station beyond the year 2000.

The detailed construction of these models are discussed in Section 3.

MISSION SCENARIO
AN OVERALL DATA SET CONTAINING A SPECIFIC COMBINATION OF MISSION MODELS & SPACE SUPPORT SYSTEM ACCOMMODATION MODE FEATURES. NEW SCENARIOS REFLECT CHRONOLOGICAL REFINEMENTS

PROGRAM OPTION
A SPECIFIC SET OF SPACE SUPPORT SYSTEM PROGRAM ELEMENTS WITH YEAR OF AVAILABILITY

MISSION MODEL
DATA SET OF THE NUMBER OF MISSIONS TO MEET USER NEEDS. IT REPRESENTS THE MASS OF ELEMENTS FOR ANY OF THE FOLLOWING MISSION TYPES: DELIVERY, SERVICE, RETRIEVAL, OR SORTIE

TRAFFIC MODEL
NUMBER OF LAUNCHES OR FLIGHTS OF STS ELEMENTS: SHUTTLE, OTV, OR TMS

MISSION PAYLOAD
END ITEM HARDWARE: MODULES, SENSORS, SATELLITES, ETC., WHICH DIRECTLY PRODUCE THE USER PRODUCT OR SERVICE

ASE
SUPPORT EQUIPMENT NEEDED TO MOUNT THE MISSION PAYLOADS IN THE SHUTTLE OR INTERFACE WITH SPACE STATION

PAYLOAD LOGISTICS SUPPORT
PROPELLANTS & SPECIAL USER-UNIQUE EQUIPMENT REQUIRED TO IMPLEMENT THE MISSION BUT NOT PART OF THE MISSION PAYLOAD

STATION LOGISTICS
RESUPPLY OF STATION CONSUMABLES

MANIFESTING
PROCESS OF INTEGRATING MISSION PAYLOADS, ASE, & PAYLOAD SUPPORT LOGISTICS TO DETERMINE TRAFFIC MODELS

TOTAL MASS FLOW
SUM OF MISSION PAYLOADS, ASE, PAYLOAD LOGISTICS SUPPORT, & STATION LOGISTICS

Figure 2-1. Mission Analysis Nomenclature

Table 2-2. Low-Inclination Missions for Scenario 6

MEDIUM MODEL												
USER AREA		YEAR										TOTAL
		91	92	93	94	95	96	97	98	99	2000	
LOW ATTITUDE	NASA SCIENCE & APPLICATIONS	5	10	8	11	11	9	12	10	10	10	96
	COMMERCIAL SPACE PROCESSING	29	29	29	30	37	35	41	49	56	72	407
	NATIONAL SECURITY	1	0	3	4	4	5	7	5	5	7	41
	NASA TECHNOLOGY DEVELOPMENT	1	2	2	3	3	0	3	2	1	2	19
	TOTAL	36	41	42	48	55	49	63	66	72	91	563
HIGH ATTITUDE	NASA SCIENCE & APPLICATIONS	0	2	0	2	2	2	1	1	2	1	13
	GOVERNMENT ENVIRONMENTAL	1	0	1	0	1	0	1	0	1	0	5
	COMMERCIAL RESOURCE OBS	0	0	0	0	0	1	0	0	0	0	1
	COMMERCIAL COMMUNICATIONS	11	21	17	15	16	21	19	11	10	12	153
	NATIONAL SECURITY	5	5	4	7	3	2	5	2	3	3	39
	GEO SERVICING	0	0	0	0	1	2	1	3	2	2	11
	TOTAL	17	28	22	24	23	28	27	17	18	18	222

Table 2-3. Medium-Inclination Missions for Scenario 6

	MEDIUM MODEL											
	USER AREA	YEAR										TOTAL
		91	92	93	94	95	96	97	98	99	2000	
LOW ALTITUDE	NASA SCIENCE & APPLICATIONS	0	0	1	1	1	1	1	1	0	2	8
	NATIONAL SECURITY	4	4	4	4	4	5	4	3	4	4	40
	TOTAL	4	4	5	5	5	6	5	4	4	6	48
HIGH ALTITUDE	NATIONAL SECURITY	5	4	7	4	5	5	5	6	4	5	50

Table 2-4. High-Inclination Missions for Scenario 6

	MEDIUM MODEL											
	USER AREA	YEAR										TOTAL
		91	92	93	94	95	96	97	98	99	2000	
LOW ALTITUDE	NASA SCIENCE & APPLICATIONS	1	2	2	4	3	3	4	3	2	2	26
	GOVERNMENT ENVIRONMENTAL	0	1	0	1	0	1	0	1	0	1	5
	COMMERCIAL RESOURCE OBS	1	2	0	1	1	1	2	1	1	0	10
	NATIONAL SECURITY	6	7	6	6	5	5	6	5	6	4	57
	TOTAL	8	12	8	12	9	10	12	10	9	7	98
HIGH ALTITUDE	NONE											0

Table 2-5. Mission Model Summary for Scenario 6A

USER AREA	MEDIUM MODEL										
	YEAR										TOTAL
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
NASA SCIENCE & APPLICATIONS	5	7	4	12	8	5	8	10	5	5	69
GOVERNMENT ENVIRONMENTAL	1	1	1	1	1	1	1	1	1	1	10
COMMERCIAL RESOURCE OBS	1	2	0	1	1	2	2	1	1	0	11
COMMERCIAL SPACE PROCESSING	6	10	9	12	18	19	22	25	25	29	175
COMMERCIAL COMMUNICATIONS	11	22	17	15	17	19	21	13	11	13	159
NATIONAL SECURITY	20	20	24	25	21	22	27	21	22	24	226
NASA TECHNOLOGY DEVELOPMENT	2	3	1	3	3	1	2	2	2	2	21
GEO SERVICING											0
MEDIUM MODEL TOTAL	46	65	56	69	69	69	83	73	67	74	671

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3.0 MISSION MODEL DEVELOPMENT

This section presents the mission model definitions and supporting rationale for each of the seven basic user areas plus GEO servicing:

- Science and Applications
- Government Environmental Observations (NOAA)
- Commercial Resource Observations
- Commercial Space Processing
- Commercial Communications
- National Security
- Technology Development
- GEO Servicing

GEO servicing could be either a commercial enterprise or simply another element of STS support systems and services. Also, it could be integrated within the appropriate user areas to reflect its application among the various users. However, to highlight the scope of GEO servicing contained in our mission model it is presented as a separate user area.

The main factors affecting the nature and number of missions in each user area are discussed along with the key variances for high and low traffic levels. These data are summarized for Scenario 6, the case with a Space Station. In addition, the expected changes to the medium model for the no-Space-Station case (Scenario 6A) are also presented.

3.1 SCIENCE AND APPLICATIONS

The Science and Applications user area is representative of the divisions of the Office of Science and Applications and for this study is divided into the following investigatory areas:

- Science
  - Planetary
  - Astrophysics
  - Life Science

- Applications
  - Resource Observation
  - Environmental Observation
  - Materials Processing
  - Communications

There are two main factors likely to affect the overall scope of the Science and Applications area. They are the projected NASA budgets and the availability of Shuttle flight assignments. Figure 3.1-1 is a Model 6 (with Space Station) composite illustration of both the historic and Rockwell International predicted budgets for the divisions which currently make up the Office of Space Science and Applications. From 1964 to the present, there has been little variation in budget in the applications flight program, applications research base, and science research base. Primary monetary variation has been in science flight programs, and the variation has been coincident with the initiation of two major programs, the Apollo and the Shuttle. It can be seen that the model designer anticipated an increase in spending at the advent of Space Station activity, which should occur, hopefully, in the 1988 to 1989 time frame.

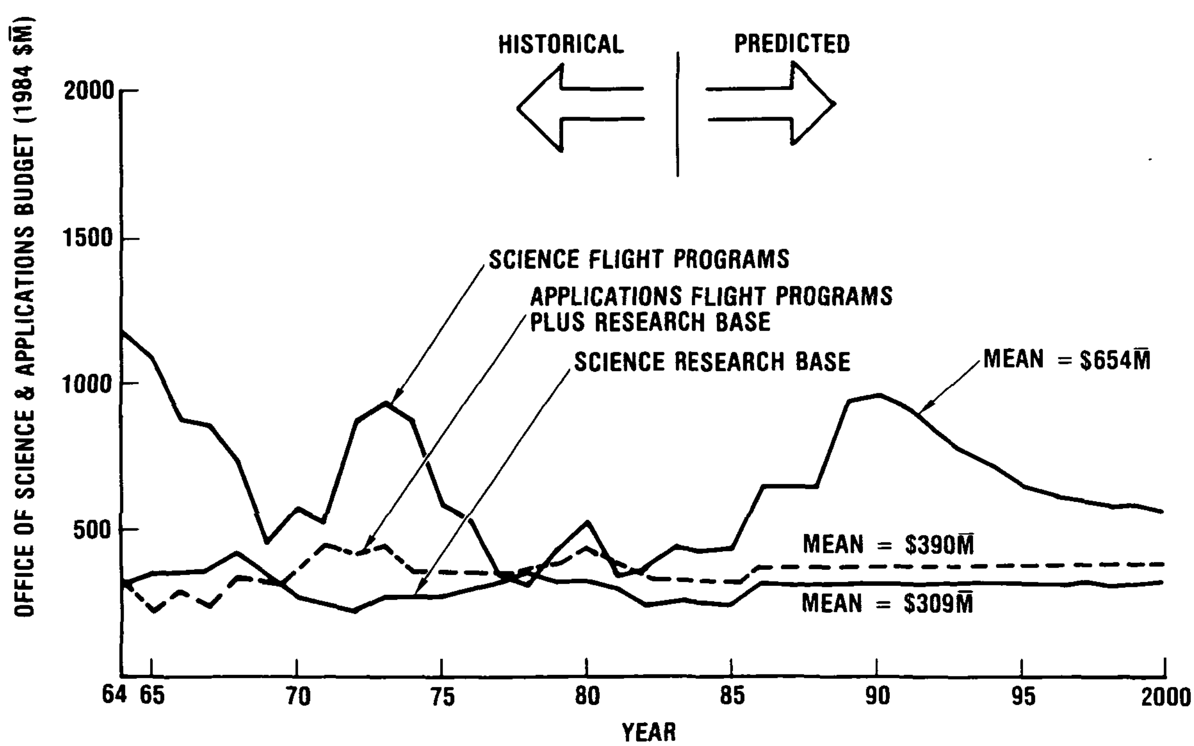

Figure 3.1-1. Historical Basis of Cost Model

The level of activity that NASA could attain in a Space Station environment, given the monies, is, however, limited by the availability of the Shuttle. Although significant monies would historically be available in the Science and Applications areas, the limitations in numbers of Shuttles substantially reduce the mission systems which can be placed on orbit or on the Space Station. This problem of course would be recognized by NASA planners and money allocations for mission systems reduced. Analysis of the November 1982, STS Flight Assignment Baseline identified the distribution of Shuttle flights among the Military, Communications, and Science and Applications user areas. Activities of the aft flight deck were ignored. Out of a possible 58 flights between 1983 and 1987, 13 were specifically dedicated to Science and Applications. Table 3.1-1 extrapolates to the year 2000 the distribution of Shuttle availability among users, assuming that the Shuttle fleet increases to five.

Table 3.1-1. Extrapolated Year 2000 Manifested Shuttle Flights

User Area	Dedicated* Per Year	Shared* Per Year
Science and Applications	5	8
Communications	2	10
Military	5	5

*Quantities are rounded off to nearest whole number

As a consequence of restrictions imposed by Shuttle availabilities, it was determined that the science flight program available funding over the years 1988 through 1995 would rise to the historic Shuttle era mean of $654 million, with applications flight programs and research base, and science research base maintaining their overall historic means. Figure 3.1-2 illustrates the projected budget funding of the divisions of the Office of Science and Applications for the years 1984 through 2000. It was to this budget that the medium model was developed and mission systems selected. The high model which formerly rose to a maximum of $950 million (Science Flight Programs) in Figure 3.1-2 was determined to be limited by Shuttle availability. Consequently the high model was made to match the medium model. The low Model 6 is assumed to be a continuance of the present budget of almost $1.08 billion.

Model 6A, the medium no-Space-Station model, established science flight program costs as the historic mean of non-program years at $425 million, and as a consequence relative to Model 6 it accomplishes considerable less data

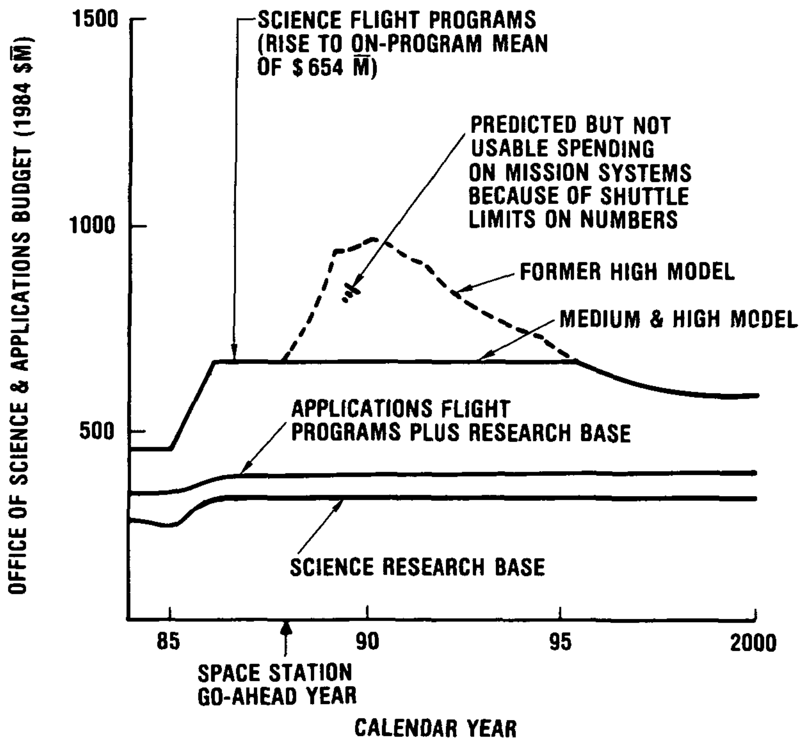

Figure 3.1-2. Predicted Medium Model Budget by Year for Office of Science and Applications (1984 Dollars)

collection, retrievals, and servicing but places almost the same imposition upon Shuttle availability. The primary distinctions between Model 6A and 6 are:

- Model 6A:
  - Reflects a decline in available funding
  - Research into long-term man-on-orbit declines, life science budget declines
  - Slower technology advancements; less probability of success
  - Fewer orbital repairs/less refurbishments/fewer retrievals
  - Systems and data collected are higher cost
  - Limitations on instrument sizes because of limits in on-orbit assembly

Model 6A maintains the identical science objectives as Model 6; however, because of budget and Shuttle restraints relative to Model 6, the objectives are pushed further downstream past the year 2000. Table 3.1-2 illustrates model expenditures.

Table 3.1-2. Cost Model Distributions Science and Applications (Average Years 1991 to 2000)

Area	Expenditures (Millions of 1984 $)			
	Model 6 With Space Station			Model 6 Without Space Station
	High	Medium	Low	Medium
Science flight programs	654	654	350	425
Science research base	309	309	309	309
Applications flight programs and research base	370	370	341	370
Predicted S&A Avg. Budget 1991 - 2000	$1,331*	$1,331	$1,000	$1,104

*If not for Shuttle transportation limitations High Model 6 Budget would rise to $1,600M

The mission models for the individual divisions of the Science and Applications user area were derived within the above spending limitations. The following subsections present the individual models, including the effects of traffic levels and the changes in the model for the Scenario 6A case, where there is no Space Station.

PLANETARY

In recent years, the trend in planetary exploration activity has been toward maintaining the high levels of achievement presently attained but at substantial reductions in cost. The primary method used to achieve this objective is to take advantage of increased spacecraft inheritance through instrument multiple use and low-cost multiple use spacecraft designs such as MMS and Pioneer buses. Additional influences being brought to bear on the planetary area is to accomplish analysis of solar system bodies and atmospheres by using variations of existing astrophysics large aperture astronomy instrumentation.

The major considerations used to define the Planetary model are:

- Continue the current emphasis on quality at a reduced cost
- Include a role for astronomy-type instruments
- Provide for the occasional "bell ringer" such as a Mars Lander/ Sampler Return

- Assure maintenance of on-going planetary scientific strategy with orderly advancement from reconnaissance through exploration to inhabitation/utilization

The National Academy of Sciences, Solar System Exploration Committee (SSEC) has been developing low-cost exploration strategies to the year 2000 time period. The Planetary models show the strong influence of the SSEC.

The transition from a low model through high model occurred as illustrated in Table 3.1-3. Table 3.1-3 also shows the traffic level rationale/trends for other Science and Applications subdivisions.

Table 3.1-4 illustrates the high, low, and medium Planetary Model 6, the case in which there is a Space Station. Essentially it follows the recommendations of the SSEC Committee with an important exception in the high and medium models. The exception is the inclusion of a Mars Lander/Sampler Return mission system which would be launched in 1999. The Mars Lander/Sampler Return mission system, with the addition of the Venus Lander/Sampler Return, represents "bell ringers" which provide high priority data to the scientific community and maintain the strategy established in the previous decade of orderly advancement of Planetary research to the utilization/habitation phase.

Table 3.1-5 illustrates the Planetary Model 6A, the case without a Space Station. It was recognized that austerity has already had a major impact upon present funding for Solar System Exploration. Reduction of funds, therefore, in the Planetary area would not be as substantial as in some of the other divisions of Science and Applications. The major change impacts the research base monies with the deletion of the Venus Lander/Sampler Return.

ASTROPHYSICS

The Astrophysics division has historically pursued a vigorous program and has maintained a budgetary level consistent for the most part with its objectives. Primary considerations during model development were:

- Continuance of historic vigorous program within budgetary commitments.
- Accommodation of priority mission systems such as Space Telescope, AXAF, and SIRTF
- Continuance of heritance to future mission systems development.
- Representative data collection across the electromagnetic spectrum
- Growth toward observatory systems consisting of large-sized, high-resolution instrumentation.
- Utilization of defined needs and strategies defined by Astrophysics Survey Committee/NAS and other recognized specialists.

Table 3.1-3. Model 6 (With Space Station) Traffic Variations

User Area	Low Model	Medium Model	High Model
Planetary	Economic and austere program which includes sharing of modified astrophysics instruments.	Low model with the addition of "Bell Ringers" such as Mars Sample Return and early spending on Venus Sample Return.	Identical to medium model.
Astrophysics	Vigorous program with most of the objectives of the Astrophysics Survey Committee and NASA Specialists.	Identical to low model.	Identical to low model.
Life Sciences	Limited volume for research, except in Medical Operations area.	Expanded volume available through addition of Plant/Animal Research Module in 1998. Volume commensurate with needs.	Expanded volume available through addition of Plant/Animal Research Module in 1996. Volume commensurate with needs.
NASA Resource Observation	No System Z, research limited to high inclination sorties and free flyers.	System Z available in 1993/1994 time frame.	Same as medium model.
NASA Environmental Observations	Absence of System Z results in dependence on sorties and free-flyers.	System Z utilized for research only in 1993-2000 time frame.	Same as medium model.
NASA Space Processing	Continuation of current efforts using Sortie Labs or aft flight deck of Shuttle at higher costs.	Advent of Space Station permits sharing of NASA commercial manufacturing facilities.	Same degree of activity as medium model.
NASA Communications	Launch of adv. communications satellite in 1997.	Launch and upgrade of adv. communications platform initiated in 1992.	Same as medium model.

Table 3.1-4. Planetary Mission Model for Scenario 6

MISSION SCENARIO 6
USER AREA· PLANETARY

X — SHUTTLE LAUNCH SE — SERVICE
S — SPACE STATION TMS — TMS NEEDED
SO — SORTIE
R — RETRIEVE

PAYLOAD/MISSION NAME	YEAR										TOTAL
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
Mars Sample Return*									X→S		1
Venus Sample Return (2005)											(2005)
LDR Modification								SE TMS			1
SIRTF Modification				SE							1
Planetary Spectroscopy Tel.		X→S TMS									1
Pluto Flyby (2001)											(2001)
Uranus Probe									X→S		1
Titan Probe							X→S				1
Mars Geochemical Orb.				X→S							1
Venus Probe					X→S						1
Comet Lander (2003)											(2003)
Near Asteroid Multi-Rendezvous					X→S						1
Mars Network						X→S					1
MEDIUM MODEL TOTAL	0	1	0	2	2	1	1	1	2	0	10
LOW MODEL TOTAL	0	1	0	2	1	1	1	1	1	0	8
HIGH MODEL TOTAL	0	1	0	2	2	1	1	1	2	0	10

Table 3.1-5. Planetary Mission Model for Scenario 6A

MISSION SCENARIO 6A
USER AREA. PLANETARY

X — SHUTTLE LAUNCH
SO — SORTIE
R — RETRIEVE
SE — SERVICE

PAYLOAD/MISSION NAME	YEAR										TOTAL
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
Mars Sample Return*									X		1
Uranus Probe									X		1
Titan Probe							X				1
Mars Geochemical Orbiter				X							1
Mars Network						X					1
Venus Probe					X						1
Near Single Asteroid Rendezvous					X						1
LDR Modification								SE			1
PST		X									1
LDCCT Modification								SE			1
Pluto Flyby (2001)											(2001)
Comet Lander (2005)											(2005)
MEDIUM MODEL TOTAL	0	1	0	1	2	1	1	2	2	0	10

* Assemble on orbit - 2 launches required

Table 3.1-6 illustrates Astrophysics Model 6 (with Space Station). An attempt was made to assure broad electro-magnetic spectrum investigation and to maintain the historic development of successor instrumentation. The model designer's objective has been to illustrate a trend toward large observatory systems. Anticipated budgetary constraints have restricted some of the mission systems such as VLST or COSMIC to launch in the post-year-2000 period.

Table 3.1-7 illustrates the Astrophysics Medium Model 6A, in which no Space Station exists. It is assumed that reduced servicing will shorten mission system life and, therefore, slow technology development and growth.

An advantage of the Space Station is that a data collection platform can be built up over a period of time on a service facility structure. When desired the built-up platform can be joined to an energy module and separated into cluster orbit. Advantages include sharing of power, data recording/transmission, cryogens, and other ancillary systems contributing to lower overall cost relative to use of an individual spacecraft bus for each payload. Candidate discipline areas and mission systems include:

Planetary Exploration		- Large-diameter reflector (LDR-20m) Planetary spectroscopy telescope (PST) Large-diameter cryogenic cooled telescope (LDCCT)
Solar Physics	ASO	- Extreme UV telescope facility (XUVTF) Pinhole occulter facility (P/OF) Solar optical telescope (SOT) Solar soft X-Ray Telescope (SSXRT)
Astronomy		- Shuttle IR telescope facility (SIRTF) Starlab telescope Large-diameter reflector (LDR-20) Potential coordination with Space Telescope

The solar physics payload can operate in conjunction with System Z to achieve many of the objectives of STO and ASTO. Figure 3.1-3 illustrates the Solar Physics Platform. Operation of the payload in the platform mode provides far more data to the user than the occasional sortie.

LIFE SCIENCE

The Space Station represents the first opportunity for NASA life science researchers to investigate the effect on man of long duration on orbit. It is anticipated that the life science research budget will increase to accommodate the investigations because the results will establish the limit to man's participation in space habitation and solar system exploration.

The guidelines used by the Life Science Model 6 developer are:

- Long-duration experiments are of prime interest, require research at the station, and will be adequately funded.

Table 3.1-6. Astrophysics Mission Model for Scenario 6

MISSION SCENARIO 6
USER AREA: PLANETARY

X — SHUTTLE LAUNCH SE — SERVICE
S — SPACE STATION TMS — TMS NEEDED
SO — SORTIE
R — RETRIEVE

PAYLOAD/MISSION NAME	YEAR										TOTAL
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
Space Telescope (1985)		X→S TMS			SE TMS		SE TMS			SE TMS	4
SIDM (1989)	R										1
AXAF (1988)	SE			SE TMS			SE TMS			SE TMS	4
LDR						X→S TMS					1
Open (1988/1989)											(1988/1989)
Starlab (1987)		SO		X→S I	SE	SE	SE	SE	SE	SE	9 (1987)
IRTF (1986)	SO	X→S I	SE	SE	SE	SE	SE	SE	SE	SE	10 (1986)
CRO				X		SE		SE		SE	4
LDCCT					X→S TMS			SE TMS			2
GRO		X		SE TMS		SE TMS		SE TMS		SE TMS	5
IR Spatial Interferometer*									X→S TMS		1
SCE		X									1
Fuse		X Geosynch.									1
GP-B (2001)											(2001)
STO			X			R					2
ASTO (57°$_1$)							X			SE	2
MEDIUM MODEL TOTAL	Totals are on the next page										
LOW MODEL TOTAL											
HIGH MODEL TOTAL											

* Assemble from two Shuttle launches

MISSION SCENARIO 6
USER AREA. PLANETARY

X — SHUTTLE LAUNCH SE — SERVICE
S — SPACE STATION TMS — TMS NEEDED
SO — SORTIE
R — RETRIEVE

PAYLOAD/MISSION NAME	YEAR										TOTAL
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
Grav. Wave Interfer. Explor. (2004)											(2004)
Molecular Line Survey Explor. (2001)											(2001)
Extrem. UV Spectromet. Explor. (2002)											(2002)
Gamma Ray Trans. Explor. (2003)											(2003)
Soft X-Ray Explor. (2004)											(2004)
SOT		X→S I	SE		SE		SE		SE		5
SSXRT ASO		X→S I	SE		SE		SE		SE		5
P/OF			X→S I	SE		SE		SE		SE	5
XUVTF				X→S I	SE		SE		SE		4
VLST (2005)											(2005)
MEDIUM MODEL TOTAL	4	7	6	7	7	7	8	7	6	8	67
LOW MODEL TOTAL	4	7	6	7	7	7	8	7	6	8	67
HIGH MODEL TOTAL	4	7	6	7	7	7	8	7	6	3	67

Table 3.1-7. Astrophysics Mission Model for Scenario 6A

MISSION SCENARIO 6A
USER AREA: ASTROPHYSICS

X — SHUTTLE LAUNCH
SO — SORTIE
R — RETRIEVE
SE — SERVICE

PAYLOAD/MISSION NAME	YEAR										TOTAL
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
SIDM (1989)	R										1
Space Telescope (1985)		X			SE			R			3
AXAF (1988)	SE			SE			SE			SE	4
LDR-10m dia.						X					1
ASO					SO		SO			SO	3
STARLAB	SO			SO				SO			3
SIRTF		SO									1
CRO				X		SE		SE		SE	4
LDCCT					X			SE			2
GRO			X		SE		SE		SE		4
SCE		X									1
FUSE		X→GEOSYNCH									1

MISSION SCENARIO 6A
USER AREA ASTROPHYSICS

X — SHUTTLE LAUNCH
SO — SORTIE
R — RETRIEVE
SE — SERVICE

PAYLOAD/MISSION NAME	YEAR										TOTAL
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
GP-B (2001)											(2001)
STO							X			R	2
ASTO (57°i) (2002)											(2002)
ASTO (POLAR i) (2003)											(2003)
VLST (2005)											(2005)
Molecular Line Survey Explor. (2003)											(2003)
Gravity Wave Interfer. (2004)											(2004)
MEDIUM MODEL TOTAL	3	4	1	3	4	2	4	4	1	4	30

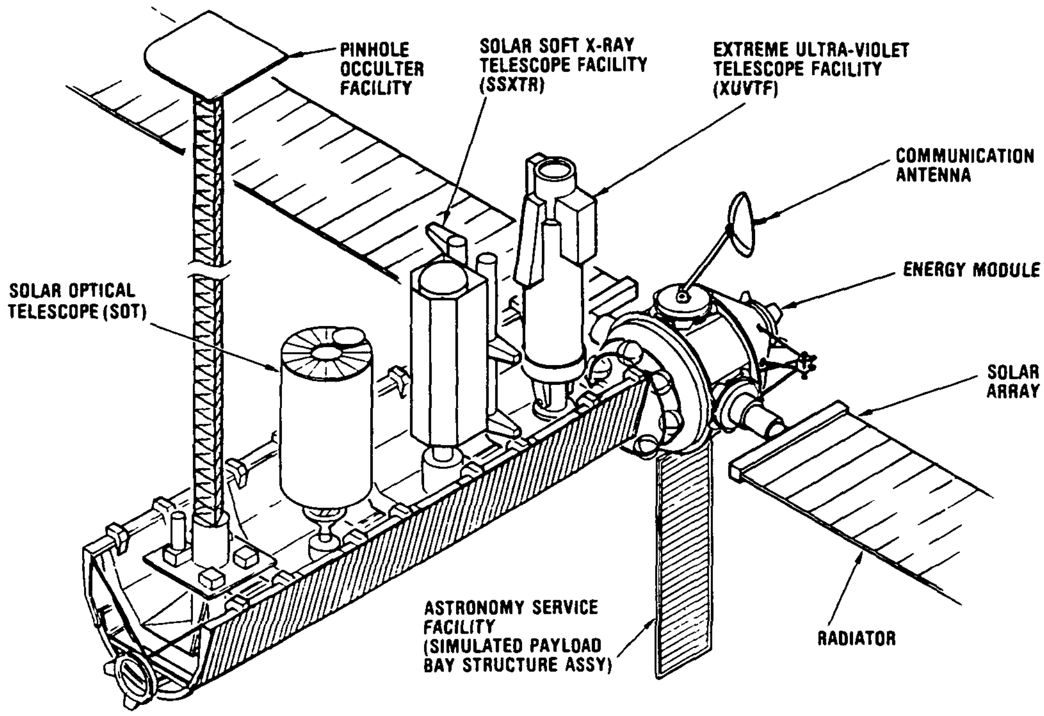

Figure 3.1-3. Solar Physics Platform

- Research will be conducted in an orderly and procedural manner, satisfy the needs of the medical operations, medical research, and plant/animal research areas, and reflect an orderly expansion of Space Station facilities.

Table 3.1-8 illustrates the Life Science Model 6.

Life science investigations are housed in three areas. The first installation is transported to orbit in 1992 as a part of the Habitation Module 2 and consists essentially of exercise equipment, medical status measurement equipment, and medicines and equipment necessary to maintain astronaut health and comfort. The facility is referred to as the Medical Operations facility and it is core installed in the Habitation Module 2.

The tunnel module, which arrives in 1993, is equipped to accommodate, and is shared by, both the medical research activity and the life science research activity. The former primarily investigated humans and the latter plants and animals. Air curtains and air separation barriers must be used to restrict particulate flow between the areas. Some equipment can be shared such as centrifuges (two will be installed in the tunnel module) and refrigerators.

Table 3.1-8. Life Sciences Mission Model for Scenario 6

MISSION SCENARIO 6 USER AREA: LIFE SCIENCE	X — SHUTTLE LAUNCH S — SPACE STATION SO — SORTIE R — RETRIEVE	SE — SERVICE TMS — TMS NEEDED I — INSTALL									
PAYLOAD/MISSION NAME	YEAR										TOTAL
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
HIGH MODEL											
Medical Oper. Area (Hab. Core Install)		SE	SE	SE	SE	SE	SE	SE	SE	SE	9
Medical Research Area											
(Tunnel Module Install)			SE	SE	SE						3
(Full Tunnel Module)						SE	SE	SE	SE	SE	5
Plant/Animal Research Area											
(Tunnel Module Installation)			SE	SE	SE						3
(Life Science Module)						X+S I	SE	SE	SE	SE	5
MEDIUM MODEL											
Medical Oper Area (Hab Cor Install)		SE	SE	SE	SE	SE	SE	SE	SE	SE	9
Medical Research Area											
(Tunnel Module Installation)			SE	SE	SE	SE	SE				5
(Full Tunnel Module)								SE	SE	SE	3
Plant/Animal Research ARea											
(Tunnel Module Installation)				SE	SE	SE	SE				4
(Life Science Module)								X+S I	SE	SE	3
LOW MODEL											
Medical Oper. Area		SE	SE	SE	SE	SE	SE	SE	SE	SE	9
Medical Res Area											
(Tunnel Module Install)			SE	SE	SE	SE	SE	SE	SE	SE	8
Plant/Animal Research Area											
(Tunnel Module Installation)				SE	SE	SE	SE	SE	SE	SE	7
MEDIUM MODEL TOTAL		1	2	3	3	3	3	3	3	3	24
LOW MODEL TOTAL		1	2	3	3	3	3	3	3	3	24
HIGH MODEL TOTAL		1	3	3	3	3	3	3	3	3	25

Table 3.1-9. Life Sciences Mission Model for Scenario 6A

MISSION SCENARIO 6A USER AREA LIFE SCIENCE	X — SHUTTLE LAUNCH SO — SORTIE R — RETRIEVE SE — SERVICE										
PAYLOAD/MISSION NAME	YEAR										TOTAL
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
Life Science Research Sorties	SO			SO				SO			3
MEDIUM MODEL TOTAL	1			1				1			3

Between 1996 and 1998, a life science plant/animal research module will be attached to the tunnel module, at which time all life science research activities will move into the newly attached area. The Medical Research facility will fully occupy the tunnel module, expanding its capability to that of a small hospital.

The life science research area is severly handicapped without some means of attaining long durations on orbit. Model 6A, the case without a Space Station, reflects a substantially lowered budget as well as low priority experiments. Table 3.1-9 illustrates life science model for Scenario 6A.

This study did not consider the new Life Science Division initiative area of Global Biology, the understanding of the biosphere and the way humans are changing the natural biogeochemical cycles.

NASA RESOURCE OBSERVATIONS

The immediate trend for the Resource Observation division is the commercialization of operational activities, which should occur in the post-1985 time frame. The model designer used the following criteria to design Model 6.

- Illustrate the impact of commercialization of the operational areas (not including modeling and data handling).
- The Resource Observation division will maintain a vigorous research activity.
- Establish the impact of System Z.
- Include priority sensors defined at the September kickoff meeting.

System Z has a number of major concepts, one of which comprises two unmanned platforms in sun synchronous orbit, 180° out of phase with each other. Potential other concepts are located at 80° and 56° inclinations. The sun-synchronous platforms are ideally located to collect data for both the resource observation and environmental observation areas. Preliminary concepting has resulted in designation of a widely diverse suite of earth-looking sensors, many of which can take the place of high-inclination free flyers. Figure 3.1-4 illustrates a System Z concept derived from our Space Station configuration. It contains the energy section (down sized) and elements of the payload support assembly (PSA) facility.

It is anticipated that in the 1995-2000 time period System Z will become the fundamental method by which earth-looking research will be conducted for applications within renewable and non-renewable resources. Essentially, the model predicts a scattering of research free flyers and sorties in the early 1990's, followed by reliance on System Z attached sensors. Table 3.1-10 illustrates the resource observation Model 6.

Table 3.1-10. *Resource Observations Mission Model for Scenario 6*

MISSION SCENARIO 6 USER AREA: RESOURCE OBSERVATION	X — SHUTTLE LAUNCH S — SPACE STATION SO — SORTIE R — RETRIEVE	SE — SERVICE TMS — TMS NEEDED I — INSTALL

PAYLOAD/MISSION NAME	YEAR 1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTAL
HIGH AND MEDIUM MODEL											
System Z*			X	SE	SE	SE	SE	SE	SE	SE	8
180° Out of Phase: System Z (180°)				X	SE	SE	SE	SE	SE	SE	7
ALOS (1989)				SE							1
Snow & Soil Moist. R&A Miss					SE						1
FIREX-B	X			SE			SE			SE	4
Magnetic Field Survey		SO									1
SAMEX-C		X+S I					SE				2
LOW MODEL											
ALOS (1989)				SE					SE		2
Snow & Soil Moisture R&A Miss.											0
FIREX-B	X			SE			SE				3
Magnetic Field Survey B		SO									1
SAMEX-C		X+S I					SE				2
GEO Science Res. Mission						SO					1
Renewable Resource Res. Mission									SO		1
MEDIUM MODEL TOTAL	1	2	1	4	3	2	4	2	2	3	24
LOW MODEL TOTAL	1	2	0	2	0	1	2	0	2	0	10
HIGH MODEL TOTAL	1	2	1	4	3	2	4	2	2	3	24

*Assemble on orbit, requires 2 Shuttle deliveries

Table 3.1-11. *Resource Observations Mission Model for Scenario 6A*

MISSION SCENARIO 6A USER AREA RESOURCE OBSERVATION	X — SHUTTLE LAUNCH SO — SORTIE R — RETRIEVE SE — SERVICE

PAYLOAD/MISSION NAME	YEAR 1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTAL
System Z			X	SE		SE		SE		SE	5
System Z (180° Out of Phase)				X	SE		SE		SE		4
Magnetic Field Survey B		SO									1
ALOS (1989)				SE							1
Installed on System Z on Noted Dates											
Snow & Soil Moisture R&A Miss. (1993/1994)			X	X							2
FIREX-B (1994/1995)				X	X						2
SAMEX-C (1996/1997)						X	X				2
MEDIUM MODEL TOTAL	0	1	2	5	2	2	2	1	1	1	17

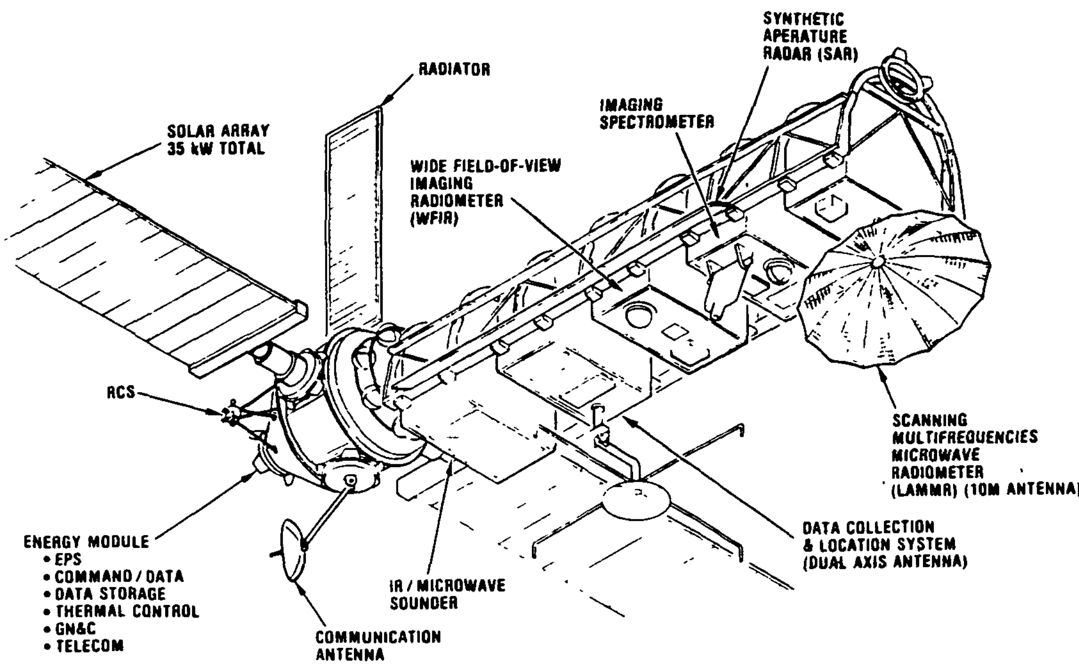

Figure 3.1-4. System Z Platform Concept

The low model represents the case of no available System Z. Since resource observation sensors require high inclination to obtain essential coverage, the Space Station cannot serve as the required platform. As a consequence reliance will be upon high inclination sorties or free flyers. Table 3.1-2 illustrates essential variations in the high, medium, and low Models 6.

As in Model 6, System Z becomes the research platform for Model 6A, Table 3.1-11. It is not anticipated that the platform would participate in commercial endeavors. Table 3.1-11 illustrates the sequence of mission systems to the System Z platform; the six mission systems should not be included in the total count as they are redundant with the platform services in the years 1994 to 2000.

NASA ENVIRONMENTAL OBSERVATIONS

NASA operational mission systems for detection and identification of weather and climate have been recently transferred to NOAA jurisdiction; additionally, there is currently an effort to commercialize all weather collection operations. Transfers of jurisdiction will not, however, impact NASA's responsibilities to conduct research and develop weather/climate prediction models. Consequently, the environmental observation Model 6 makes use of System Z for research activities.

The guidelines which were defined to construct the environmental observation Model 6 are:

- Include impact of transfer of operational satellites to NOAA.
- Illustrate effects of growing model maturity through using mission systems with focused objectives.
- Allow for NASA maintenance of on-going research activities.
- Include impact of System Z as a research sensor platform.
- Use priority sensors defined in September kick-off briefing to contractors.

It is not anticipated that System Z will be used as a NOAA or military weather data collection platform. Like the resource observation mission systems, polar, sun-synchronous orbits are necessary to provide 100-percent earth coverage daily for weather detection and research into weather/climate prediction. Little to no interactive activity in space with man is anticipated although potential real time interactive ground links to operators could, under certain conditions, be necessary.

Table 3.1-12 illustrates the NASA Environmental Observation Model 6. The environmental observation research area will make major use of the System Z. The transport of environmental sensing instruments to System Z is part of the service traffic to the platform shown in the high and medium model 6 for resource observations. Much greater activity (12 vs. 3) is shown for the low model Scenario 6 because, as a consequence of not having a System Z, reliance is upon free fliers and sorties. The primary differences between the high, low, and medium models are listed in Table 3.1-2.

The absence of a Space Station has a minimum impact on environmental observation missions system development. Major impact on Model 6A is anticipation of a budget reduction because of the general austerity, which historically exists in the absence of major program development, and because predictive weather models will be nearing maturity within 10 years and necessary data inputs can be more specifically identified. Table 3.1-13 summarizes the NASA environmental observations mission model for Scenario 6A.

NASA SPACE PROCESSING

The model developer assumed that commercial endeavors were in full swing on Space Station in 1991. NASA efforts would co-exist with the commercial and be primarily limited to research into future applications and processes. Table 3.1-14 illustrates Model 6. Basic differences between the high, low, and medium models are illustrated in Table 3.1-2.

Table 3.1-15 illustrates Model 6A. The model developer assumes primary reliance upon sorties in the absence of Space Station.

Table 3.1-12. Environmental Observations Mission Model for Scenario 6

MISSION SCENARIO 6
USER AREA NASA ENVIRONMENTAL OBSERVATIONS

X — SHUTTLE LAUNCH SE — SERVICE
S — SPACE STATION TMS — TMS NEEDED
SO — SORTIE
R — RETRIEVE

PAYLOAD/MISSION NAME	YEAR 1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTAL
HIGH AND MEDIUM MODEL											
Orbital Lidar Facility		SO									1
Solar Constant Explorer (SCE)			X								1
TOPEX/Windscatt (1990)					SE						1
(Install on Z) Adv. LARS						X	X				2
LOW MODEL											
Orbital Lidar Facility		SO		SO			SO			SO	4
Solar Constant Explorer (SCE)			X			SE			SE		3
OADS								X			1
TOPEX/Windscatt (1990)					SE					SE	2
Adv. LARS						X					1
Envir Obs Research Sortie								SO			1
MEDIUM MODEL TOTAL		1	1	0	1	1	1	0	0	0	5
LOW MODEL TOTAL		1	1	1	1	2	1	2	1	2	12
HIGH MODEL TOTAL		1	1	0	1	1	1	0	0	0	5

Table 3.1-13. Environmental Observations Mission Model for Scenario 6A

MISSION SCENARIO 6A
USER AREA NASA ENVIRONMENTAL OBSERVATIONS

X — SHUTTLE LAUNCH
SO — SORTIE
R — RETRIEVE
SE — SERVICE

PAYLOAD/MISSION NAME	YEAR 1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTAL
Orbital Lidar Facility											
[Install on System Z (1992/1993)]			X	X							2
Solar Const. Explorer		X									1
Adv. Lower Atm. Res. Sensor Suite											
[Install on System Z (1998/1999)]								X	X		2
MEDIUM MODEL TOTAL	0	1	1	1	0	0	0	1	1	0	5

Table 3.1-14. Space Processing Mission Model for Scenario 6

MISSION SCENARIO 6
USER AREA NASA SPACE PROCESSING

X — SHUTTLE LAUNCH SE — SERVICE
S — SPACE STATION TMS — TMS NEEDED
SO — SORTIE
R — RETRIEVE

PAYLOAD/MISSION NAME	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTAL
MEDIUM AND HIGH MODEL											
Processing Facility Equipment/ Supplies	SE	SE	SE	SE	SE	SE	SE	SE	SE	SE	10
LOW MODEL											
Space Process Sorties		SO		SO		SO		SO		SO	5
MEDIUM MODEL TOTAL	1	1	1	1	1	1	1	1	1	1	10
LOW MODEL TOTAL	0	1	0	1	0	1	0	1	0	1	5
HIGH MODEL TOTAL	1	1	1	1	1	1	1	1	1	1	10

Table 3.1-15. Space Processing Mission Model for Scenario 6A

MISSION SCENARIO 6A
USER AREA NASA SPACE PROCESSING

X — SHUTTLE LAUNCH
SO — SORTIE
R — RETRIEVE
SE — SERVICE

PAYLOAD/MISSION NAME	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTAL
Material Processing Sortie	SO			SO				SO			3
MEDIUM MODEL TOTAL	1	0	0	1	0	0	0	1	0	0	3

NASA COMMUNICATIONS APPLICATIONS

The model developer assumed that, by 1990, a vigorous commercial communications satellite industry would be well developed. NASA's role in respect to these activities would be to demonstrate technologies for new types of services and applications techniques which would either extend life or increase reliability without major impacts upon communications satellite costs.

Table 3.1-16 illustrates the model developed by the model developer. The models are identical for the high and medium mission activity levels. Model 6A, Table 3.1-17 is identical to the low model for Scenario 6. Both are affected by the assumption that GEO servicing is unavailable before the year 2000 (assumption applied to both the low model for Scenario 6 and the medium model for Scenario 6A.

SCIENCE AND APPLICATIONS SUMMARY

Tables 3.1-18 through 3.1-24 define the numbers of deliveries to space, services in space, retrievals to earth, and sortie missions for the low, medium, or high models for Scenario 6--Science and Applications with a Space Station.

Table 3.1-25 presents the same data for the Model 6A--Science and Applications without a Space Station for each investigative area.

Tables 3.1-16. *Communications Applications Mission Model for Scenario 6*

MISSION SCENARIO 6
USER AREA. NASA COMMUNICATIONS APPLICATIONS

X — SHUTTLE LAUNCH
S — SPACE STATION
SO — SORTIE
R — RETRIEVE
SE — SERVICE
TMS — TMS NEEDED

PAYLOAD/MISSION NAME	YEAR 1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTAL
HIGH AND MEDIUM MODELS											
Adv. Communications Platform		X		SE		SE		SE		SE	5
LOW MODEL											
Adv. Communications Satellite							X				1
MEDIUM MODEL TOTAL	0	1	0	1	0	1	0	1	0	1	5
LOW MODEL TOTAL	0	0	0	0	0	0	1	0	0	0	1
HIGH MODEL TOTAL	0	1	0	1	0	1	0	1	0	1	5

Tables 3.1-17. *Communications Applications Mission Model for Scenario 6A*

MISSION SCENARIO 6A
USER AREA NASA COMMUNICATIONS APPLICATIONS

X — SHUTTLE LAUNCH
SO — SORTIE
R — RETRIEVE
SE — SERVICE

PAYLOAD/MISSION NAME	YEAR 1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTAL
Advanced Communications Satellite							X				1
MEDIUM MODEL TOTAL	0	0	0	0	0	0	X	0	0	0	1

Table 3.1-18. Categories of Missions--Planetary

MISSION SCENARIO 6 SCIENCE & APPLICATIONS USER AREA PLANETARY		YEAR										TOTAL
		91	92	93	94	95	96	97	98	99	2000	
HIGH MODEL	DELIVERIES		1		1	2	1	1		2		8
	SERVICING				1				1			2
	RETRIEVAL											
	SORTIE											
	TOTAL	0	1	0	2	2	1	1	1	2	0	10
MEDIUM MODEL	DELIVERIES		1		1	2	1	1		2		8
	SERVICING				1				1			2
	RETRIEVAL											
	SORTIE											
	TOTAL	0	1	0	2	2	1	1	1	2	0	10
LOW MODEL	DELIVERIES		1		1	1	1	1		1		6
	SERVICING				1				1			2
	RETRIEVAL											
	SORTIE											
	TOTAL	0	1	0	2	1	1	1	1	1		8

Table 3.1-19. Categories of Missions--Astrophysics

MISSION SCENARIO 6 SCIENCE & APPLICATIONS USER AREA ASTROPHYSICS		YEAR										TOTAL
		91	92	93	94	95	96	97	98	99	2000	
HIGH MODEL	DELIVERIES	1	7	3	2	1	1	1	1	1		18
	SERVICING			3	5	6	5	7	6	5	8	45
	RETRIEVAL	1					1					2
	SORTIE	2										2
	TOTAL	4	7	6	7	7	7	8	7	6	8	67
MEDIUM MODEL	DELIVERIES	1	7	3	2	1	1	1	1	1		18
	SERVICING			3	5	6	5	7	6	5	8	45
	RETRIEVAL	1					1					2
	SORTIE	2										2
	TOTAL	4	7	6	7	7	7	8	7	6	8	67
LOW MODEL	DELIVERIES	1	7	3	2	1	1	1	1	1		18
	SERVICING			3	5	6	5	7	6	5	8	45
	RETRIEVAL	1					1					2
	SORTIE	2										2
	TOTAL	4	7	6	7	7	7	8	7	6	8	67

Table 3.1-20. Categories of Missions--Life Sciences

MISSION SCENARIO 6 SCIENCE & APPLICATIONS USER AREA LIFE SCIENCE		YEAR										TOTAL
		91	92	93	94	95	96	97	98	99	2000	
HIGH MODEL	DELIVERIES						1					1
	SERVICING		1	3	3	3	2	3	3	3	3	24
	RETRIEVAL											
	SORTIE											
	TOTAL	0	1	3	3	3	3	3	3	3	3	25
MEDIUM MODEL	DELIVERIES								1			1
	SERVICING		1	2	3	3	3	3	2	3	3	23
	RETRIEVAL											
	SORTIE											
	TOTAL	0	1	2	3	3	3	3	3	3	3	24
LOW MODEL	DELIVERIES											
	SERVICING		1	2	3	3	3	3	3	3	3	24
	RETRIEVAL											
	SORTIE											
	TOTAL	0	1	2	3	3	3	3	3	3	3	24

Table 3.1-21. Categories of Missions--Resource Observations

MISSION SCENARIO 6 SCIENCE & APPLICATIONS USER AREA NASA RESOURCE OBSERVATIONS		YEAR										TOTAL
		91	92	93	94	95	96	97	98	99	2000	
HIGH MODEL	DELIVERIES	1	1	1	1							4
	SERVICING				3	3	2	4	2	2	3	19
	RETRIEVAL											
	SORTIE		1									1
	TOTAL	1	2	1	4	3	2	4	2	2	3	24
MEDIUM MODEL	DELIVERIES	1	1	1	1							4
	SERVICING				3	3	2	4	2	2	3	19
	RETRIEVAL											
	SORTIE		1									1
	TOTAL	1	2	1	4	3	2	4	2	2	3	24
LOW MODEL	DELIVERIES	1	1									2
	SERVICING				2			2		1		5
	RETRIEVAL											
	SORTIE		1				1			1		3
	TOTAL	1	2	0	2	0	1	2	0	2	0	10

Table 3.1-22. Categories of Missions--Environmental Observations

MISSION SCENARIO 6 SCIENCE & APPLICATIONS USER AREA NASA ENVIRONMENTAL OBSERVATIONS		YEAR										TOTAL
		91	92	93	94	95	96	97	98	99	2000	
HIGH MODEL	DELIVERIES			1								1
	SERVICING					1						1
	RETRIEVAL											
	SORTIE		1									1
	TOTAL	0	1	1	0	1	0	0	0	0	0	3
MEDIUM MODEL	DELIVERIES			1								1
	SERVICING					1						1
	RETRIEVAL											
	SORTIE		1									1
	TOTAL	0	1	1	0	1	0	0	0	0	0	3
LOW MODEL	DELIVERIES			1			1		1			3
	SERVICING					1	1			1	1	4
	RETRIEVAL											
	SORTIE		1		1			1	1		1	5
	TOTAL	0	1	1	1	1	2	1	2	1	2	12

Table 3.1-23. Categories of Missions--Space Processing

MISSION SCENARIO 6 SCIENCE & APPLICATIONS USER AREA SPACE PROCESSING		YEAR										TOTAL
		91	92	93	94	95	96	97	98	99	2000	
HIGH MODEL	DELIVERIES											
	SERVICING	1	1	1	1	1	1	1	1	1	1	10
	RETRIEVAL											
	SORTIE											
	TOTAL	1	1	1	1	1	1	1	1	1	1	10
MEDIUM MODEL	DELIVERIES											
	SERVICING	1	1	1	1	1	1	1	1	1	1	10
	RETRIEVAL											
	SORTIE											
	TOTAL	1	1	1	1	1	1	1	1	1	1	10
LOW MODEL	DELIVERIES											
	SERVICING		1		1		1		1		1	5
	RETRIEVAL											
	SORTIE											
	TOTAL	0	1	0	1	0	1	0	1	0	1	5

Table 3.1-24. Categories of Missions--Communications Applications

MISSION SCENARIO 6 SCIENCE & APPLICATIONS USER AREA NASA COMMUNICATIONS APPLICATIONS		YEAR										TOTAL
		91	92	93	94	95	96	97	98	99	2000	
HIGH MODEL	DELIVERIES		1									1
	SERVICING				1		1		1		1	4
	RETRIEVAL											
	SORTIE											
	TOTAL	0	1	0	1	0	1	0	1	0	1	5
MEDIUM MODEL	DELIVERIES		1									1
	SERVICING				1		1		1		1	4
	RETRIEVAL											
	SORTIE											
	TOTAL	0	1	0	1	0	1	0	1	0	1	5
LOW MODEL	DELIVERIES							1				1
	SERVICING											
	RETRIEVAL											
	SORTIE											
	TOTAL	0	0	0	0	0	0	1	0	0	0	1

Table 3.1-25. Categories of Missions for Scenario 6A

MISSION SCENARIO 6A SCIENCE & APPLICATIONS		YEAR										TOTAL
		91	92	93	94	95	96	97	98	99	2000	
PLANETARY	DELIVERIES		1		1	2	1	1	2	2		10
	SERVICING											
	RETRIEVAL											
	SORTIE											
	TOTAL	0	1	0	1	2	1	1	2	2	0	10
ASTROPHYSICS	DELIVERIES		3	1	1	1	1	1				8
	SERVICING	1			1	2	1	2	2	1	2	12
	RETRIEVAL	1							1		1	3
	SORTIE	1	1		1	1		1	1		1	7
	TOTAL	3	4	1	3	4	2	4	4	1	4	30
LIFE SCIENCES	DELIVERIES											
	SERVICING											
	RETRIEVAL											
	SORTIE	1			1				1			3
	TOTAL	1	0	0	1	0	0	0	1	0	0	3

Table 3.1-25. Categories of Missions for Scenario 6A (Cont)

MISSION SCENARIO 6A SCIENCE & APPLICATIONS		YEAR 91	92	93	94	95	96	97	98	99	2000	TOTAL
RESOURCE OBS	DELIVERIES			1	1							2
	SERVICING			1	4	2	2	2	1	1	1	14
	RETRIEVAL											
	SORTIE		1									1
	TOTAL	0	1	2	5	2	2	2	1	1	1	17
ENVIRONMENTAL OBS.	DELIVERIES		1									1
	SERVICING			1	1				1	1		4
	RETRIEVAL											
	SORTIE											
	TOTAL	0	1	1	1	0	0	0	1	1	0	5
SPACE PROCESSING	DELIVERIES											
	SERVICING											
	RETRIEVAL											
	SORTIE	1			1				1			3
	TOTAL	1	0	0	1	0	0	0	1	0	0	3

Table 3.1-25. Categories of Missions for Scenario 6A (Cont)

MISSION SCENARIO 6A SCIENCE & APPLICATIONS USER AREA PLANETARY		YEAR 91	92	93	94	95	96	97	98	99	2000	TOTAL
NASA COMMUNICATIONS APPLICATIONS	DELIVERIES							1				1
	SERVICING											
	RETRIEVAL											
	SORTIE											
	TOTAL	0	0	0	0	0	0	1	0	0	0	1

Table 3.1-25. Categories of Missions for Scenario 6A (Cont)

MISSION SCENARIO 6A SCIENCE & APPLICATIONS USER AREA PLANETARY		YEAR 91	92	93	94	95	96	97	98	99	2000	TOTAL
NASA COMMUNICATIONS APPLICATIONS	DELIVERIES							1				1
	SERVICING											
	RETRIEVAL											
	SORTIE											
	TOTAL	0	0	0	0	0	0	1	0	0	0	1

3.2 NOAA ENVIRONMENTAL OBSERVATION

Model 6 illustrates the transfer of weather-data-collection operations to NOAA. It is anticipated that the current constellations of satellites would continue to serve collection objectives to the year 2000, although continually modified and updated through the result of NASA research endeavors. Table 3.2-1 illustrates Model 6. There is no distinction among the high, medium, and low models.

The model is not impacted by the absence of Space Station; therefore, Model 6A is identical to Model 6.

Table 3.2-1. Governmental Environmental Observations Mission Model

MISSION SCENARIO 6 & 6A
USER AREA NOAA ENVIRONMENTAL OBSERVATIOUS

X — SHUTTLE LAUNCH SE — SERVICE
S — SPACE STATION TMS — TMS NEEDED
SO — SORTIE
R — RETRIEVE

PAYLOAD/MISSION NAME	YEAR 1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTAL
NOAA-TIROS-METSAT		1		1		1		1		1	5
GOES	1		1		1		1		1		5
MEDIUM MODEL TOTAL	1	1	1	1	1	1	1	1	1	1	10
LOW MODEL TOTAL	1	1	1	1	1	1	1	1	1	1	10
HIGH MODEL TOTAL	1	1	1	1	1	1	1	1	1	1	10

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3.3 COMMERCIAL RESOURCE OBSERVATIONS

The guidelines which the Model 6 designer used are:

- A vigorous commercial activity is anticipated.
- Satellite mission system types will be responsive to needs from which profits can be derived.
- Mission systems will reflect technology availabilities outside the military area.
- Primary research into development of techniques will be performed by NASA.

It was recognized early that it would be difficult (if not impossible) to define the specific satellite types that existing or future corporations would utilize in the 1991 to 2000 period. However, by investigating long-term needs in terms of technology availabilities, we could make some decisions as to possible trends. It was established that probable tasks and satellite/mission system types would encompass:

- Land mapping, health and status of agriculture, forest resources, and rangeland resources, fresh water resources, wildlife, and fresh water fisheries resources, coast and estuarine mapping, geologic mapping, economic geology (minerals and chemicals) an advanced Landsat type mission system.
- Ocean water and fisheries resources, fish school tracking (tracking fish oil)--an advanced Seasat type mission system.
- Ocean status sensing (optimizing the paths by which large ocean transport systems cross the ocean) a sea track type satellite/mission system.
- Urban needs, pollution, distributions of resources and populations, unique needs of local governments or private individuals--a land services type mission system.

Table 3.3-1 illustrates Model 6, and Table 3.3-2 illustrates Model 6A.

3.4 COMMERCIAL SPACE PROCESSING

The commercial space processing mission model is governed by (1) the willingness of MPS champions/enterpreneurs to underwrite the cost to produce marketable products (those with price/cost benefits), (2) the possibility of reducing the time from experiment concept to full-scale production, and (3) the value of knowledge gained from removing the effects of gravity (zero

Table 3.3-1. Commercial Resource Observations/Mission Model for Scenario 6

MISSION SCENARIO 6
USER AREA: COMMERCIAL RESOURCE OBSERVATIONS

X — SHUTTLE LAUNCH
S — SPACE STATION
SO — SORTIE
R — RETRIEVE
SE — SERVICE
TMS — TMS NEEDED

PAYLOAD/MISSION NAME	YEAR										TOTAL
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
Commercial Adv. Landsat		X		X	X		X				4
Commercial Seasat	X	X					X	X	X		5
Commercial Seatrack				X	X	X					3
Commercial Land Services						X					1
MEDIUM MODEL TOTAL	1	2	0	1	1	2	2	1	1	0	11
LOW MODEL TOTAL	0	1	0	0	1	0	2	1	1	0	6
HIGH MODEL TOTAL	1	2	0	2	2	2	2	1	1	0	13

Table 3.3-2. Commercial Resource Observations Mission Model for Scenario 6A

MISSION SCENARIO 6A
USER AREA: COMMERCIAL RESOURCE OBSERVATIONS

X — SHUTTLE LAUNCH
SO — SORTIE
R — RETRIEVE
SE — SERVICE

PAYLOAD/MISSION NAME	YEAR										TOTAL
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
Commercial Adv. Landsat		X		X	X		X				4
Commercial Seasat	X	X					X	X	X		5
Commercial Seatrack						X					1
Commercial Land Services						X					1
MEDIUM MODEL TOTAL	1	2	0	1	1	2	2	1	1	0	11

buoyancy in space) in order to improve the understanding of ground processes. In the first case, return on investment (ROI) is the driver. In the second case, decreased time to achieve full production gives the manufacturer a major advantage over his competitors. In the third case, the driver is the potential improvements in ground-produced products and associated technologies. Rockwell developed a six-step approach to construct the commerical space processing model. The steps are shown below and discussed in what follows:

- International market surveys/analyses
- Material screening/selection
- MPS facility evaluation/selection
- Mission model logic
- Hardware/mass element definition
- Economic viability

INTERNATIONAL MARKET SURVEYS/ANALYSES

Rockwell enlisted the aid of subcontractors for the market surveys. The subcontractors, in turn, hired consultants and issued subcontracts to cope with specialized areas. The heirarchy is delineated in Table 3.4-1, and is largely self-explanatory.

Table 3.4-1. Rockwell Subcontracts/Consultants

GTI Corporation

- Total market analysis
- Material screening/selection
- Subcontract to Battelle, Columbus
- Consultants
    - E. Kern & Associates
    - M. Bier (Biologicals)

MRA

- NASA/JEA (Shuttle Tests of LPEE* furnace (GaAs))
- Subcontract to MIT (R&D on furnace)
- Consultants
    - Technology insights (GaAs and Type III-V XTALS)

o LPEE technical data

Dr. M. Bier

- RIEF** analysis

*LPEE - Liquid phase electroepitaxial
**RIEF - Recycled isoelectric focusing

The GTI Corporation and MRA, Inc., conducted the market survey. GTI concentrated on all areas studied (metals and alloys, glasses and ceramics, electronic materials, and biologicals), while MRA specialized in GaAs (the prime semiconductor product envisioned for space production) and other attractive semiconductors (Types III-V).

Rockwell surveyed the biotechnologies through the GTI subcontract and the services of Dr. M. Bier. Dr. M. Bier also provided a detailed analysis of MPS, comparing recycled isoelectric focusing (RIEF) and zone electrophoresis (CFES).

MATERIAL SCREENING/SELECTION

A logic diagram (Figure 3.4-1) was used to define all major data needed to qualify specific candidates for large-scale MPS.

The MPS factory logic diagram shows market definition as the first step. This led to grouping a large number of candidate materials into four basic classes: metals/alloys, electronic materials, glass/ceramics, and biologicals.

The material candidates were then subjected to a filtering process to eliminate products with questionable risk and payoff. A product was rejected if the revenue was less than $100 million annually when averaged over ten years. This criterion alone eliminated many candidate materials for factory production in an assumed Shuttle-launched free-flyer satellite. The rationale which prompted this filtering was that the development, fabrication, and verification cost would exceed $100 million for a satellite with solar arrays, batteries (uninterrupted power), thermal radiators, a propulsion system for orbit makeup, momentum wheels, and attitude control.

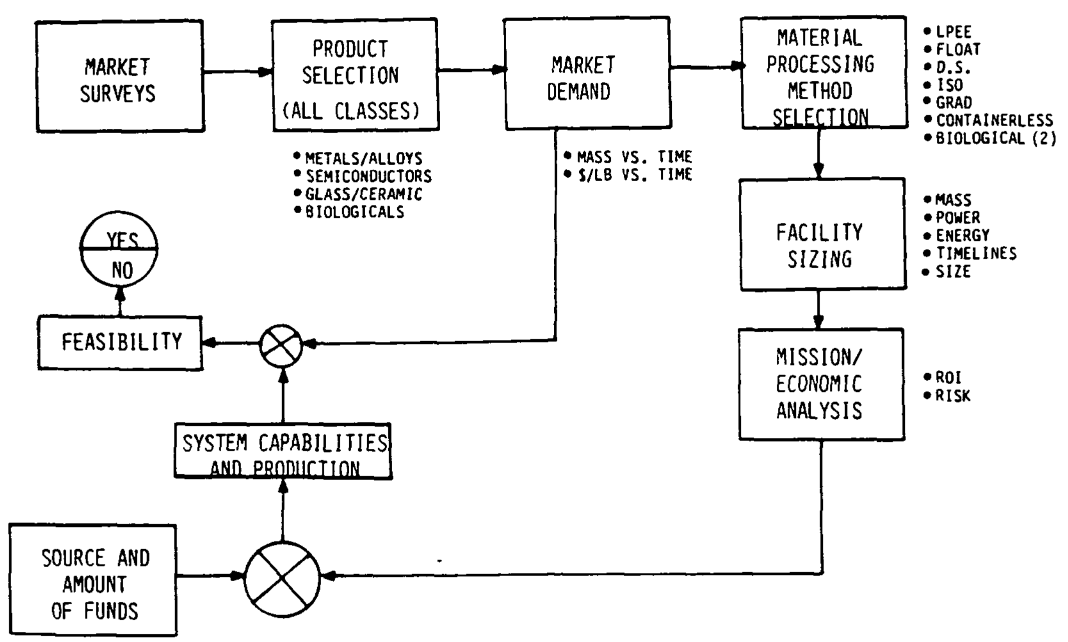


Figure 3.4-1. MPS Factory Logic Diagram

Product Selection

Metals/Alloys/Glasses/Ceramics. No metal/alloy or glass/ceramic candidates were found that would justify production in space. To be commercially viable, all candidates would have needed government support in addition to industrial and/or venture capital. If iron could be turned into gold on an EDO mission, the investors would lose money because of launch, integration, and venture capital costs.

Electronic Materials--Semiconductors. Only a few specific candidates out of several hundred were identified for attempted production in space. In each case, either the product or production capability was uniquely improved. Also, production of some high quality (defect-free) materials, such as indium phosphide (InP), apparently can be done only in space. InP, used in fast MOS circuits, is a strong candidate for future computers and should sell for about $0.5 million per pound when free of defects.

In general, viable materials for space production exhibit a high selling price per unit of product. They are, however, associated with a certain risk from ground competitors who persistently look for breakthroughs.

There are, at present, at least 15 suppliers of GaAs material. The technology is rapidly advancing in both complexity and diversification of product applications. This was particularly evident at the Fourth Annual Gallium Arsenide Symposium, held in New Orleans on November 9-11, 1982.

Currently, GaAs technology is moving from the discrete transistor to components and circuits of increasing complexity, including both analog and digital IC's. This effort is encouraged by the recognition of increasing numbers of market applications.

GaAs chips (developed or under development) include A/D and D/A converters, gate arrays, multipliers, high-speed memory, digital logis, variable alternators, front end filter correlators, programmable filters, phase shifters, tunable sources, receiver front ends, power amplifiers, charged coupled devices, and phased-array transmit/receive modules.

If the possibility of near perfect GaAs integrated circuits (IC's) from space production is considered, and extrapolated to other follow-on material combinations together with advanced circuit concepts, the possibility for improved performance and new device-circuit interaction scenarios becomes virtually endless. In these directions, we can look beyond the VHSIC era.

Table 3.4-2 presents typical semiconductor candidates, along with the three selected for production. HgCdTe and InP are more important in the last half of the nineties. GaAs is the major near-term candidate.

Table 3.4-3 summarizes many of the promising applications.

Table 3.4-2. Material Selection for Space Manufacturing

Typical material candidates include:

Si	InAlP	All potential, high-priority candidates for future semiconductor production relating to:
InP	InAs	
GaP	InGaAs	• Optical fiber systems
AlAs	InGaAsP	• Lasers
AlGaAsSb	InGaP	• Nonlinear optics
AlGaSb	InP	• Electro- and acousto-optics
AlSb	InSb	• IR optical components
GaAlAs		• Gamma detectors
GaAsP		
GaAsSb		
GaN		
GaSb		

Selected candidates

- GaAs
  - Microwave circuitry
  - High-speed signal processing circuits
- CdTe substrates
  - Hg, CdTe infrared (IR) arrays
- InP
  - Near IR optical devices
  - High-speed signal processing circuits

Table 3.4-3. GaAs Technology Applications

A. Government/military

Space-based radar
Wideband electronic warfare
Command and control communications
Weapon target acquisition, guidance, and control
Secure communication systems
Military satellite communications
Expendable jammers
Expendable decoys
Phased array radar
Missile seekers
Wideband early warning
Anti-jam data links

B. Electronic data processing

Faster, more powerful computers

C. Communications

Satellites
Fiber optic systems
Secure communications

D. Business

Systems and equipment for "office of the future"

E. Consumer

Home information systems

Market Demand (Semiconductors)

Government/Military. Applications for space-produced GaAs in this market segment should expand throughout the 1990's, driven by needs to exploit the full potential of GaAs. The market drivers will be military weapon system applications, government/military communications, and high-speed signal data processing requirements. GaAs technology will enable the advancement of sophisticated systems requiring small size, fast speeds, high-frequency response, communications security, low-power consumption, and radiation and nuclear-pulse hardness.

Electronic Data Processing (EPS). Faster computers will be spurred by international competition. Throughout the 1990's, development of high-speed random access memories (RAM's), gate arrays, and custom IC's will drive this market segment.

Communications. The quality of earth-produced GaAs is expected to support most applications in this market segment throughout most of the 1990's. However, building upon the broad GaAs technology base funded by the government, this market segment is expected to see rapid growth beginning in the late 1980's. Applications will include microwave communications, pay TV, CATV, digital microwave radio (DMR), and other low volume uses. Fiber optic communications and direct satellite-to-house communications (12 GHz) will grow into major market drivers.

Table 3.4-4 summarizes the projected MPS market for GaAs.

Table 3.4-4. Projected Market for Gallium Arsenide

Year	$/kg	User Demand (kg)			Market Value (10^6 Dollars)		
		High	Medium	Low	High	Medium	Low
1990	800K	46	34	22	36.8	27.2	17.6
1991	635K	124	78	52	78.74	49.5	33.0
1992	497K	238	142	94	118.2	70.5	46.7
1993	406K	390	230	152	158.3	93.3	61.7
1994	350K	622	355	235	217.7	124.2	82.2
1995	310K	940	535	350	291.4	165.8	108.5
1996	284K	1420	790	509	403.2	224.3	144.5
1997	264K	2100	1140	735	554.4	300.9	198.0
1998	258K	3000	1630	1040	774.0	420.5	268.3
1999	252K	4300	2300	1450	1,083.6	579.6	365.4
2000	250K	6020	3225	2015	1,505.0	806.2	503.7

Biological Products--Proteins and Enzymes. Genetic engineering and monoclonal antibody endeavors were found to be moving ahead rapidly in what is a revolution in applied biology. The impact of genetic engineering is affecting many areas, such as:

- Protein engineering to produce specific catalysts
- Improvements of plants
- Manipulations of microorganisms for increased production of antibiotics and many other specialty chemicals, such as amino acids
- Ultimate objective of some research is the production of large volumes of commodity chemicals which are now derived from petroleum.

The health aspects of this revolution in biology survived the initial screening--the surviving candidates are the numerous biomedicines listed in Table 3.4-5.

The state of the art in genetic engineering is currently too primitive even to visualize its future scope. It is possible that MPS may provide unexpected advantages in the growing or reproduction of plant seedlings, separation of modified cells, cloning of cells, or even growth of complete organs, such as bones. However, these scenarios are currently a little beyond the horizon and are therefore not applicable to the filtering criteria.

On the other hand, a promising biomedicine; interferon, easily survived the criteria and was selected to be the second major MPS candidate (GaAs the first). The reasons are as follows:

- The production technology is most advanced.
- Economic benefits are easiest to specify.
- Unit cost is very high.
- There is an enormous premium on increases in purity.

The potentially high economic payoff (ROI) resulting from increases in purity, and to increases in throughput, are the primary drivers for producing the final purification step in space.

Currently, interferon is a focus for intensive clinical testing. The estimated total production of purified interferon will be in the order of 100 gms in 1983 (which is 10 percent of the current U.S. annual demand) and should increase logarithmically over the next few years. It is also estimated that the demand will peak toward the mid-nineties to 50 to 60 kg/year, thereafter decreasing as other therapeutic agents are developed. Refer to Figures 3.4-2 and -3. The current yield (from earthbound processes) of pure interferon (of the purity demanded for clinical testing) is of the order of 5 percent and it is projected to increase to as high as 20 percent over the next decade. This projection for earthbound processing is, however, considered optimistic.

Table 3.4-5. Pharmaceutical Product Characteristics

Large Human Polypeptides Potentially Attractive for Biosynthesis

	Amino Acid Residues	Molecular Weight
Prolactin	198	
Placental lactogen	192	
*Growth hormone	191	22,005
Nerve growth factor	118	13,000
Parathyroid hormone (PTH)	84	9,562 bovine
Proinsulin	82	
Insulin-like growth factors (IGF-1 & IGF-2)	70, 67	7,649, 7,471
Epidermal growth factor		6,100
*Insulin	51	5,734
Thymopoietin	49	
Gastric inhibitory polypeptide (GIP)	43	5,104 porcine
*Corticotropin (ACTH)	39	4,567 porcine
Cholecystokinin (CCK-39)	39	
Big gastrin (BG)	34	
Active fragment of PTH	34	4,109 bovine
Cholecystokinin (CCK-33)	33	3,918 porcine
*Calcitonin	32	3,421 human 3,435 salmon
Endorphins	31	3,465
*Glucagon	29	3,483 porcine
Thymosin-α	28	3,108
Vasoactive intestinal peptide (VIP)	28	3,326 porcine
*Secretin	27	
*Active fragment of ACTH	24	
Motilin	22	2,698

*Currently used in medical practice
Source: Office of Technology Assessment

Major Diseases for Which Vaccines Need to be Developed

PARASITIC DISEASES

Hookworm
Trachoma
Malaria
Schistosomiasis
Sleeping sickness

VIRUSES

Hepatitis
Influenza
Foot-and-mouth disease (for cloven-hoofed animals)
Newcastle disease virus (for poultry)
Herpes simplex
Mumps
Measles
Common cold rhinoviruses
Varicella-zoster (shingles)

BACTERIA

Dysentery
Typhoid fever
Cholera
Traveler's diarrhea

Source: Office of Technology Assessment

Table 3.4-5. Pharmaceutical Product Characteristics (Cont)

Diseases Amenable to Drugs Produced by Genetic Engineering in the Pharmaceutical Industry

Disease or Condition	Drug Potentially Produced by Genetically Engineered Organism
Diabetes*	Insulin
Atherosclerosis	Platelet-derived growth factor (PDGF)
Virus diseases	Interferon
Influenza	
Hepatitis	
Polio	
Herpes	
Common cold	
Cancer	Interferon
	Hodgkin's disease
	Leukemia
	Breast cancer
Anovulation	Human chorionic gonadatropin
Dwarfism*	Human growth hormone
Pain	Enkephalins and endorphins
Wounds and burns	Human growth hormone
Inflammation, rheumatic diseases*	Adrenocorticotrophic hormone (ACTH)
Bone disorders, e.g., Paget's disease*	Calcitonin and parathyroid hormone
Nerve damage	Nerve growth factor (NGF)
Anemia, hemorrhage	Erythropoietin
Hemophilia*	Factor VIII and Factor IX
Blood clots*	Urokinase
Shock*	Serum albumin
Immune disorders	Cytokines

*Indicates diseases currently treated by the drugs listed
Source: Office of Technology Assessment

Pharmaceuticals: Large Molecules

Product Category	End Use
PEPTIDE HORMONES	
Insulin	Control of diabetes
Endorphins	Analgesics, narcotics, prophylactics
Enkephalins	Analgesics, narcotics, prophylactics
ACTH*	Diagnostic: adrenal instability
Glucagon	Therapeutic: diabetes-induced hypoglycemia
Vasopressin	Therapeutic: antidiuretic
Human growth hormone	Therapeutic: dwarfism
ENZYMES	
Glucose oxidase	Diagnostic: measurement of blood sugar
Urokinase	Therapeutic: antithrombotic
Asparaginase	Therapeutic: antineoplastic
Tyrosine hydroxylase	Therapeutic: Parkinson's disease
VIRAL ANTIGANS	
Hepatitis viruses	Vaccine
Influenza viruses	Vaccine
Herpes viruses	Vaccine
Varicella virus	Vaccine
Rubella virus	Vaccine
Reoviruses	Vaccine: common cold
Epstein-Barr virus	Vaccine: infectious mononucleosis, nasopharyngeal carcinoma, Burkitt lymphoma
MISCELLANEOUS PROTEINS	
Interferon	Control of infectious diseases
Human serum albumin	Therapeutic: shock and burns
Monoclonal antibodies	Diagnostics: hepatitis, cancer, etc., therapeutics
GENE PREPARATIONS	
Sickle-cell anemia	Control of hereditary disorder
Hemophilias	Control of hereditary disorder
Thallasemias	Control of hereditary disorder

*Adrenocorticotropic hormone
Source: Genex Corp.

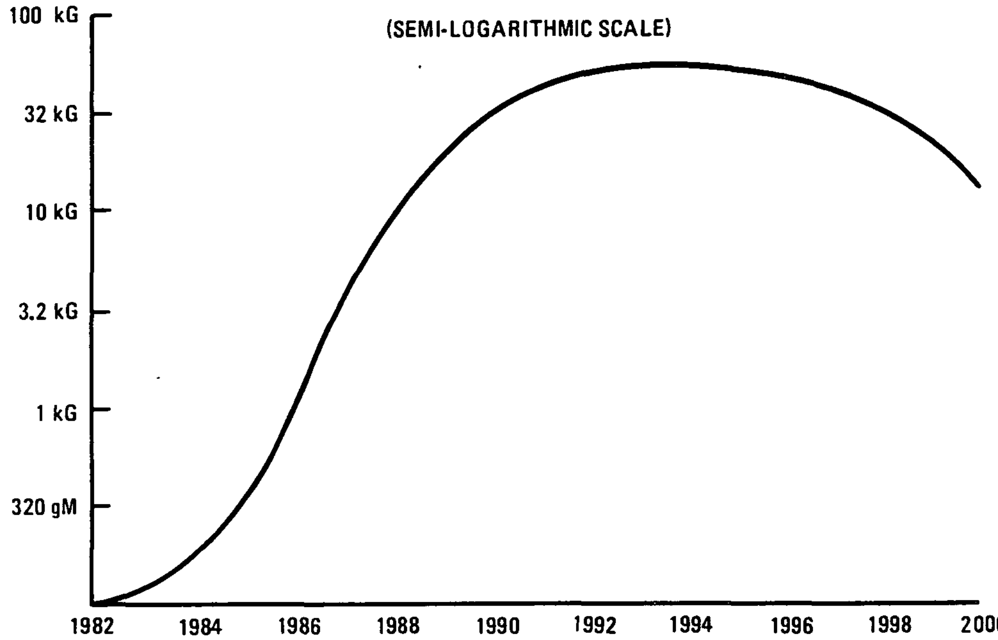


Figure 3.4-2. Projected World-Wide Production of Pure Interferon

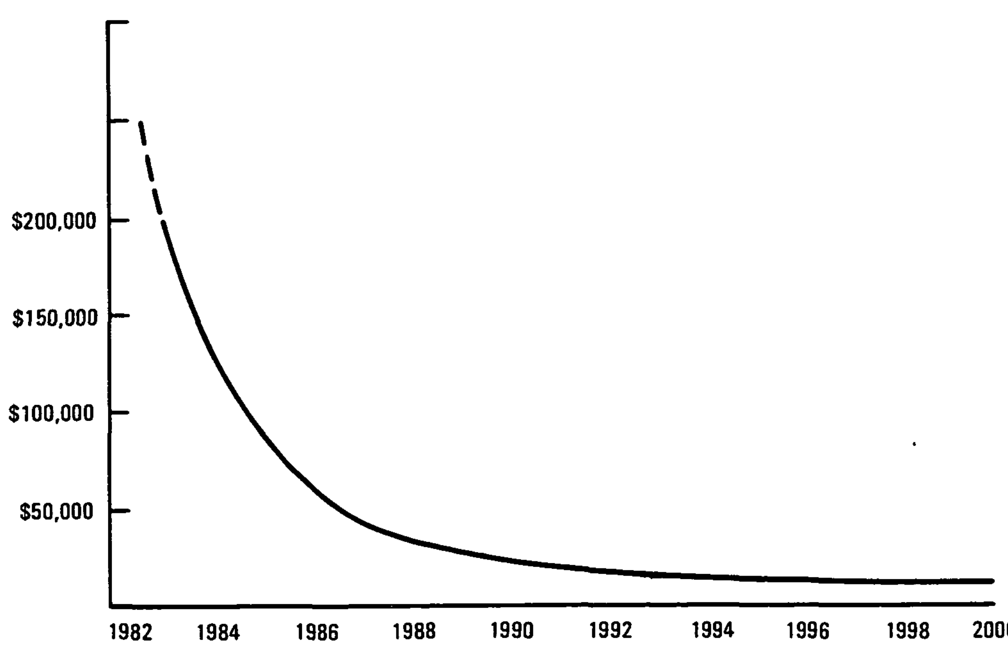


Figure 3.4-3. Projected $/Gram Value of Pure Interferon

Several new pharmaceuticals developed by genetic engineering have already been licensed or are in clinical testing: human insulin, various interferons, human growth hormone, foot and mouth virus vaccine, and urokinase. A far wider range of hormones, vaccines, human blood proteins, and other biologics is in various states of advanced research.

Table 3.4-6 compares the projected growth of biologicals in the year 2000 with the current market and Table 3.4-7 summarizes the survey/screening findings.

Table 3.4-6. Projected Growth of Selected Markets Involving Applications of Genetic Engineering

Produce Category	Current Market $ Millions	Projected Market in 2000 AD $ Millions
Miscellaneous proteins	500	2,000
Gene preparations	-	1,000
Short peptides	10	4,000
Peptide hormones	430	2,000
Totals	940	9,000

Table 3.4-7. Material Screening/Selection

Survey Findings

- No metals/alloys/glasses/ceramics justify commercial MPS factories (inadequate price/cost benefits)
- Two classes of attractive candidates
  1. Semiconductors--gallium arsenide (GaAs) and types III-V XTALS
  2. Pharmaceuticals--interferon, a primary candidate
- Viable materials for MPS exhibit a high $/lb in 1983 dollars

  If gold = 1, then
  Flawless GaAs = 100, and
  Pure interferon = 20,000
- Ground competitors constitute a major risk
- Interferon carries an additional risk--it can deteriorate (several hundred million dollars may be at stake)

Survey Deduction

- The high raw-product cost necessitates the presence of man to insure against deterioration of pharmaceuticals in case of malfunction

MPS FACILITY EVALUATION/SELECTION

The processes for manufacturing the selected candidates (gallium arsenide and interferon) and related materials (shown in Tables 3.4-8 and -9) are all dependent on microgravity conditions. With respect to MPS this implies an absence of convection, sedimentation/buoyancy, and body force pressures. Convection is fluid flow caused by temperature differences. Sedimentation/buoyancy is the separation or settling of matter because they contribute to flaws in crystals, and may reduce the achievable purity in ground processing of pharmaceuticals. With respect to pressure, container contamination is inevitable on the ground when container molecules react with high temperature melt molecules. In space, containerless processing is relatively easy since the product is suspended freely and held together by surface tension.

On-Board Semiconductor Factory/Experiment Facility

A liquid phase electroepitaxial (LPEE) furnace, of the type under development by NASA/MRA/MIT, was selected for production of GaAs and other compatible Type II - V crystals. It was also used for experiments.

The empirical data for growing GaAs crystals were obtained from MIT documents which gave a basic equation relating crystal growth rate and current density. A set of estimating relationships derived from the data was used in designing LPEE furnace parameters. The furnace sizing work will be published in a separate IR&D report. It is sufficient to say here that production of nearly flawless GaAs may require that accelerations be $\leq 10^{-5}$ g. This has yet to be determined.

Because the Space Station is manned, it cannot provide a steady-state 10^{-5} g environment, whereas this could be achieved on an unmanned satellite. However, for several hours each day on the station, during periods of sleep, it was assumed possible to maintain a low-level acceleration ($\sim 10^{-5}$ g) environment. This would not be practical for periods of months or even days without special equipment. The selection of GaAs processing equipment on the station, however, was influenced by this assumption.

It was determined from the surveys that user demands for GaAs did not justify the cost of a separate satellite until 1995. Since the LPEE furnace was adaptable to high-speed runs, it was designed to take advantage of the assumed space station daily quiet period. During a period of 5.64 hours, enough ingot could be produced to yield two pounds of finished wafers per day and 44 usable seed crystals. Further, the cash flow analysis showed that after a year of operation, beginning either in 1991 or 1992, it was making a profit.

The same furnace, but operating at half the current density, was used in the free flyer. The physical characteristics of these furnaces are compared in Table 3.4-8.

When the high-speed space station furnace was used for experiments the growth time was reduced to 2.86 hours and only six ingots were produced compared to 44. This required a second quiet period in 48 days of each year, since it was desired to produce 288 experiments (ingots) per year. Refer also to Table 3.4-9.

Table 3.4-8. Gallium Arsenide Furnace Comparison

Space Station Furnace	Satellite Furnace
1. Load (regulator) power - 10 kW	12.37 kW
2. Cycle time* - 5.64 hours	5.91 days → X 5 cycle (once-a-month service)
3. Energy/cycle - 5.64 kWh	1,754 kWh
4. Crystals/cycle - 44	240
5. Crystals/ingot - one (27.7%)	Ten (67.8%)
6. Production/year (353 days) - 2,693 lb (ingot) 748 lb (XTAL)	3,434 lb (ingot) 2,330 lb (XTAL)
7. Weight of raw material/ingots = 3,231 lb/year** cargo up	4,120 lb/year** cargo up
8. Cartridge weight/cycle = 68.6 lb (44)	517 lb (24 cartridges) 2,580-lb/resupply
9. kWh/kg (XTAL)*** = 58.66	98.9
10. kg/kWh (XTAL) = 0.0170	0.010

*One run/day
**20% added for containers
***20 A/cm^2 growth current at 10A/cm^2 growth current

Table 3.4-9. Space Station Attached MPL Facility Characteristics

Facility	Bio Lab	Bio Factory	XTAL Lab	XTAL Factory
Weight (lb)	5,000	14,400	2,550*	2,550*
Size (ft)	8D x 4	8D x 10	2 x 2 x 4	2 x 2 x 4
Power (kW)	2	4	10	10
Energy (kWh/cycle)	12	16D	28.6	56.4
Cycle time (hr)	15	40	3.36	6.14
Crew time (hr/cycle)	9	8.4	1.50	2.5
Max production (lb/yr)		252		748
No. of exp/yr	28		288 exps*** (48 cycles)	

*One facility
**Based on $1.5 to $2.0M/experiment
***6 experiments/cycle

Onboard Interferon Factory/Experiment Facility

Rockwell employed the services of Dr. M. Bier to assist in selecting the most practical method for producing interferon and other attractive biomedicines. The two key processes, continuous flow zone electrophoresis (CFES) and recycling isoelectric focussing (RIEF), are compared in Table 3.4-10.

Based on this information and Bier's associated report, it was decided to use RIEF on the station for both production and experiment. A RIEF facility could run for days and still recover from whatever accelerations occurred when they were over, whereas with CFES the characteristic low resolution would be further degraded with each successive disturbance, and because of the low flow rate, the susceptible period could take several weeks.

The presence of man is believed to be essential because of the complexity and diversity of the steps involved in electrophoresis. Although automation is not impossible, there is an overwhelming reason why man will be indispensible in any forseeable space installation (including CFES). The value of the input material to be processed is likely to exceed $100 million or more, which is a large sum at risk. It is unlikely that man will not be used as the versatile monitor of its safety.

The following scenario is envisaged.

Materials to be purified will be sent aloft in a concentrated form, as solid powders, frozen paste, or highly concentrated frozen or refrigerated solution. The choice between these possibilities will depend on the stability

Table 3.4-10. Comparison of Two Promising Processes for Space Manufacturing

Continuous Flow Zone Electrophoresis	Recycling Isoelectric Focusing
1. Separation is based on differences in migration velocity of components.	1. Separation is based on differences in isoelectric points of components.
2. It is a rate process; recirculation is impossible.	2. A steady state is achieved, rendering recirculation possible.
3. Single pass has to be used with carefully optimized parameters.	3. Recirculating regime does not require parameter optimization.
4. It requires homogenous buffers.	4. Buffers capable of establishing a stable pH gradient are essential.
5. It is a low resolution method.	5. It is a high resolution method.
6. Resolution impaired by gravity disturbance.	6. Resolution independent of gravity disturbances.
7. Primary use is for cell separations.	7. Primary use is for proteins and peptides.
8. It requires cooling of apparatus.	8. Joule heating is dissipated in the recirculating path--not in the apparatus.
9. Optical scanning possible, but no feedback optimization.	9. Resolution independent of gravity disturbances.

of the protein in question. Due to the relative scarcity of space flights, the material may have to be stored for several months on the ground before being lofted into space.

Large volumes of water are necessary for processing. This water can be obtained in space from fuel cells and recycling. Its functions will be constitution of various buffers for electrophoresis and buffers for the dissolution and reconstitution of the protein sample. This will require the addition of premeasured buffering salts to successive batches of water.

Reconstitution of protein solutions from powder or frozen paste is the next step. Following reconstitution, the solution will most likely have to be centrifuged and/or filtered, to remove denatured particulate matter and to assure sterility. As the stability of many proteins in solution is limited, protein reconstitution may have to be repeated at varying time intervals. Moreover, the capacity of the centrifuge and/or filters may be limited and they may have to be refurbished.

The electrophoretic apparatus must be primed and its operation initiated.

Upon collection of fractions, they may have to be processed to assure maximum stability of the protein. This may comprise such diverse steps as the addition of stabilizers, freezing, freeze-drying, ultrafiltration, sterile filtration, etc.

A drawing of the RIEF apparatus is shown in Figure 3.4-4.

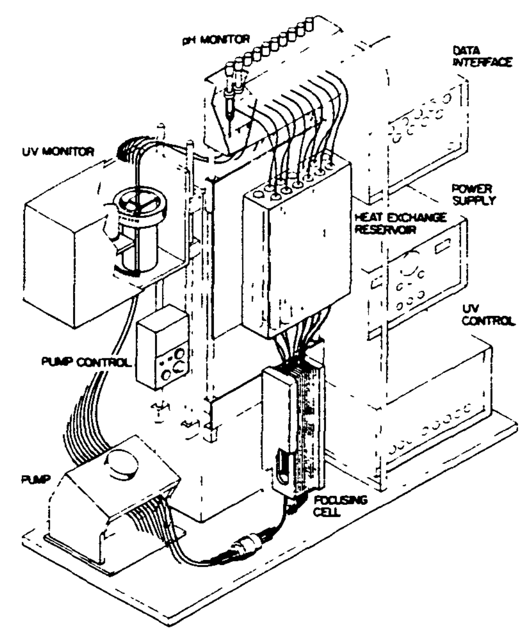


Figure 3.4-4. Schematic Presentation of the RIEF Apparatus

Selected physical characteristics of the RIEF Factory and Experiment Facilities are presented in Table 3.4-9.

A breakdown of typical equipment required for the RIEF facilities is shown in Table 3.4-11.

McDonnell Douglas Pharmaceutical Satellite Factories

Factory sizing (mass, power, energy, volume, and process time lines) was accomplished for only RIEF. The CFES factory sizing was not accomplished because this is an on-going effort of McDonnell Douglas/Johnson and Johnson, with certain proprieties.

The main advantage of continuous flow electrophoresis is the gentleness of the process, which makes it of paramount importance for the purification of delicate structures (such as mammalian cells or antihemophilic Factor-8) whether of natural origin or modified through genetic engineering. It is foreseen that separation of modified mammalian cells will be a challenge for the next generation of bioprocessors.

The first step in equipment verification for continuous flow electrophoresis was conducted by McDonnell Douglas in the Shuttle mid deck. These experiments established that the elimination of gravity effects enabled the processing of more concentrated samples than can be achieved in terrestrial operations, thereby increasing the throughput. The same benefits may accrue to isoelectric focusing with the additional advantage of enhanced purity.

Table 3.4-11. Typical Bioresearch Lab Equipment

1.	Isoelectric or electrophoresis separation--purification assembly
2.	Tissue--cell culture assembly including incubators, nutrient cell and environmental control
3.	Water purification, storage and recycle unit
4.	Refrigeration--cryogenic unit for freezing, freeze drying and storage
5.	Centrifuge assembly
6.	Pressure-vacuum assembly
7.	Waste management unit
8.	Refrigerated transport unit
9.	Control and data display--storage assembly
10.	Power conditioning and control assembly
11.	Thermal control assembly
12.	Sample defrost unit
13.	3-axis acceleration package, 0-50 Hz

However, Rockwell has no knowledge of the products proposed by McDonnell Douglas for production in space.

A summary of selected product categories, key candidates for factory production, the associated MPS processes recommended, and the process advantages are presented in Table 3.4-12.

Table 3.4-12. MPS Facility Evaluation/Selection

Selected Products	Selected Process	Process Advantage
Semiconductors		
• GaAs • X,CdTe • InP • Type III-V Materials (Table 3.4-2)	LPEE	• Short runs practical • Low energy • NASA/MRA JEA • Under development (MIT)
Pharmaceuticals		

• Proteins and peptides (Table 3.4-5)
  • Interferon
  • Monoclonal antibody prod.
  • Genetic engineering products
	RIEF	• High resolution and throughput
		• Recovery from "G" disturbances
		• Feedback optimization
		• Recirculation
		• Minimum risk with man

• Cell separations • Sensitive proteins (Antihemophilia VIII)	CFES	• High throughput • Gentle conditions

MISSION MODEL LOGIC

It is convenient to refer to Table 3.4-13 which summarizes the role played by the Space Station in the MPS scenario. The station offered direct benefits to both satellite factories and on-board factory/experiment facilities.

Referring to the table (station attached column), the RIEF factory and laboratory were provided with a water recycling (distillation) system which saved transporting thousands of pounds of water every few months. Redundant refrigerators were also provided because of the limited shelf life of pharmaceuticals when warmed. In addition to verifying production feasibility the biolab was used to establish risk management practice. With over $100 million in pharmaceuticals on board at any one time, the most effective insurance against product deterioration derives from the man/machine interfaces and resources required for risk management.

Table 3.4-13. Station-Aided MPS Scenario

SPACE STATION ATTACHED	FREE-FLYING FACILITIES
BIO LAB (RIEF) PURPOSE • PRODUCTION FEASIBILITY • SMALL-SCALE PRODUCTION • RISK MANAGEMENT PRACTICE BIO FACTORY (RIEF) PRODUCTION • INTERFERON • MONOCLONAL ANTIBODY AND GENETIC ENGINEERING PRODUCTS CRYSTAL LAB (LPEE) PURPOSE • FLAWLESS SAMPLES • PRODUCTION FEASIBILITY CRYSTAL FACTORY (LPEE) PRODUCTION • GaAs (1991-1994) • TYPES III-V (1995-2000) ON-BOARD MISSION ACTIVITIES • WATER RECYCLING • CARTRIDGE LOADING/UNLOADING • MAN/MACHINE INTERFACES • SATELLITE/SPARES STORAGE & C/O	McDAC/J&J BIOMED FACTORY (CFES) • TEN SPACECRAFT (1989-2000) • TWO SPACECRAFT PER PRODUCT • PRODUCTS PROPRIETARY • TMS SERVICE - RESUPPLY EVERY 6 MONTHS/SPACECRAFT (~5000 lb water recycle at Space Station) - PROPELLANT RESUPPLY EVERY 4 YEARS) - FACTORY MODULE EVERY 5 YEARS CRYSTAL FACTORY (LPEE) • TWO SPACECRAFT (1995-2000) • GaAs (ONLY PRODUCT) • TMS SERVICES - RESUPPLY EVERY 30 DAYS (Cartridges unloaded/loaded at station) • BATTERY (NiH) EXCHANGE EVERY 3 YEARS • PROPELLANT RESUPPLY EVERY 4 YEARS

The biolab was also used to respond to the numerous anticipated requirements for small quantities of medicine. For example, a single gram of a pure product might provide 10^4 to 10^5 doses, which could satisfy the world's annual demand.

The RIEF factory was used to produce interferon at the projected annual worldwide demand level as shown in Table 3.4-14. Three other TBD major products were also purified, such as the products of monoclonal antibodies. Based on interferon production requirements, this is sufficient to keep the facility operating at close to 75-percent capacity.

The LPEE furnace served as both a factory and an experiment facility. The crystal laboratory produced sufficient ingot for six finished (5-in.) wafers per 2.86 hour cycle. What are presumed to be nearly flawless crystals were produced at the rate of 288 wafers per year (48 cycles). At the same time the feasibility of mass-producing any attractive candidate could be determined.

One advantage of an on-board, high-speed crystal factory is that the initial investment is small compared to a free flying factory. In the 1992 to 1994 era, the user demand and gross revenue did not justify a satellite, although the on-board facility was able to meet the demand (Table 3.4-15) and make a profit after one year of operation. This is illustrated in the next section. In 1995 a fleet of two satellite factories was used to produce the GaAs demands out through 2000, and thereby relieved the station from this

Table 3.4-14. Worldwide Demand/Productions/Cost Data for Interferon

YEAR	WW USER NEED-PURE PRODUCT KG/YR	GROSS VALUE $M/YR	TREATMENT DOLLARS/DOSE	BULK MATERIAL PER RUN (KG)	WATER USED (KG)	AVERAGE PROCESS TIME .(HRS)
1983	0.12	25	21.0	0.24	24	10.44
1984	0.17	23	14.0	0.34	34	14.79
1985	0.35	31	9.0	0.70	70	30.45
1986	0.90	58	6.5	1.80	180	78.3
1987	3.0	135	4.5	6.0	600	261.0
1988	9.0	315	3.5	18.0	1800	783.0
1989	18.0	450	2.5	36.0	3600	1566.0
1990	30.0	660	2.2	60.0	6000	2610.0
1991	43.0	817	1.9	86.0	8600	3741.0
1992	50.0	850	1.7	100.0	10000	4350.0
1993	56.0	896	1.6	112.0	11200	4872.0
1994	58.0	870	1.5	116.0	11600	5046.0
1995	56.0	784	1.4	112.0	11200	4872.0
1996	50.0	700	1.4	100.0	10000	4350.0
1997	45.0	630	1.4	90.0	9000	3915.0
1998	35.0	490	1.4	70.0	7000	3045.0
1999	25.0	350	1.4	50.0	5000	2175.0
2000	15.0	210	1.4	30.0	3000	1305.0

Table 3.4-15. GaAS Production on Space Station and Free Flyer

	GaAs RAW MATERIAL/ INGOT WGT* - LB			CARTRIDGE BUILDUP LB/YEAR			
YEAR	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW	
1990							
1991	2529	1994	1014	5	6	6	ON-BOARD SPACE STATION FACTORY
1992	2529	1994	1014	—	—	—	
1993	2529	1994	1014	—	—	—	
1994	2419	1994	949	3358	—	490	
1995	3656	2080	1413	1870	963	475	FREE FLYING SATELLITE FACTORY
1996	5522	3072	2055	1870	1940	475	
1997	8167	4433	2967	1870	1940	475	
1998	11667	6339	4199	1870	1940	475	
1999	16723	8945	5854	1870	1940	475	
2000	23411	12542	8135	—	—	—	

* EQUAL UP/DOWN WEIGHT - RAW MATERIAL/INGOTS. TWENTY PERCENT PENALTY FOR CONTAINERS. CARTRIDGES REMAIN ON ORBIT (IN SERVICE).

task. The station factory was then used to produce Type III - V crystals from 1995-2000. The demand for these more exotic semiconductors, in terms of GaAs demand, increased from 10 percent in 1995 to 35 percent in 2000.

A key advantage of the station for crystal processing in space is that the cartridges can be brought to a work area where the raw materials and ingots are exchanged. This is done in lieu of bringing the loaded cartridges back to the ground each time for unloading and loading. This reduces the weight transported (by the Shuttle) by a factor of ten since cartridges weigh nine times as much as the ingots. Table 3.4-15 shows the required weights transported up and down by the Shuttle in order to produce the user requirements (finished wafers) shown in Table 3.4-4. The cartridges are only taken up once.

Table 3.4-16 shows the user demand (in kg) for Type III - V semiconductors as projected for the latter nineties. The cartridge weights (not shown) increase to 138 pounds in 1995 because of the addition of a second furnace to run simultaneously. A third furnace in 2000 increases the onboard cartridge weight to 254 pounds.

Tables 3.4-17, -18, and -19 show the number of factory/laboratory facilities, and number of products/experiments in mission model 6, along with supporting rationale.

Table 3.4-20 gives the number of Shuttle delivered parcels to the station for station-attached production and R&D, and for FF services and resupplies. This is also summarized for the high and low models.

Table 3.4-16. Space Station On-Board Type III-V Semiconductor Production

YEAR	TYPE II - VI USER DEMAND (KG)			TRANSPORTED WGT. (LB)* (LB)		
	HIGH	MEDIUM	LOW	HIGH	MEDIUM	LOW
1994	31	-	18	1442[a]	-	578[a]
1995	94	54	35	1442[a]	1137[a]	578[a]
1996	213	119	76	2025	1137[a]	723
1997	420	228	147	3993	2168	1398
1998	750	408	260	7130	3879	2472
1999	1290	690	435	12264	6560	4136
2000	2107	1129	705	20031	10733	6702

* EQUAL UP/DOWN WEIGHT - RAW MATERIALS/INGOTS
TWENTY PERCENT PENALTY FOR CONTAINERS INCLUDED.

a INCLUDES BACKLOG FROM 1990 - 1994

Table 3.4-17. Space Station R&D Laboratory Mission Model

	Mission Model		
	Low	Medium	High
Biolab			
• Feasibility experiments*	2	4	8
• Small scale production**	12	24	36
Rationale	High cost of raw product and dollar risk limits experiment activity	Assumes operation at twice the low model capacity with increased financing	Increase reflects addition of second MPS module (1996)
	**There will be a high demand for production of small quantities of various purified medicines.		
Crystal lab			
• Development of know-how to produce Type III-V Xtals*	12/month 2 runs/mo	24/month 4 runs/mo	36/month 6 runs/mo
Rationale	Limited by duration of available quiet periods and electric power available	Assumes twice the electric power density in available quiet periods (40 amp/cm^2)	Assumes further increases in available power density (X 3) (60 A/cm^2)
*Prior to factory production			

Table 3.4-18. Space Station Factory Mission Model

	Mission Model		
	Low	Medium	High
SS Crystal Factory			
• Total No. furnaces	2	3	4
• Number of products	3	6	8
Rationale	Minimum No. of candidate products currently identified (GaAs, GaP, HgDcTe)	Most likely number based on projected future projects (e.g., military, etc.)	Optimistic projections envision new fiber optic (laser) and detector materials
SS Biomed Factory			
• Total No. facilities	1	1	2
• Number of products	2	4	8
Rationale	Two products pay for the entire factory/experiment module	Full capacity of factory--maximum dollar payoff and self-supporting	Two facilities operating at full capacity--maximum payoff to entrepreneurs and potential benefits to mankind

Table 3.4-19. Free-Flying Factory Mission Model

	Mission Model		
	Low	Medium	High
FF pharm. factories (MDAC)			
• Total No. satellites	6	10	12
• Number of products	3	5	6
• Backup satellites	3	5	6
Rationale	3 key products in demand in the nineties	Most likely number based on $ risk and user survey	High-payoff products reduced to 6 out of 13
FF crystal factories	(6.8 kW)	(12.4 kW)	(12.4 kW)
• Total No. satellites	3	2	3
• Number of products	1	1	1
Rationale*	Small satellites (3 kW) lower costs low pessimistic market	Larger satellites matched to market economy of scale	Meets optimistic market by adding one more satellite
*Requires optimizing the iterations of mission/economic/"factory sizing"			

Table 3.4-20. Commercial Space Processing Mission Model

		1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	TOTALS		
STATION ATTACHED		1	0	0	0	1	0	0	0	0	1	3	3	4
PHARM R&D		5	5	5	5	5	5	5	5	5	5	50	30	70
PHARM PRODUCTION		9	8	8	8	8	8	8	8	.8	8	81	21	121
CRYSTAL R&D		4	4	4	4	4	4	4	4	4	4	40	20	60
CRYSTAL PRODUCTION		7	7	7	7	6	6	8	12	19	25	106	119	105
PHARM FREE-FLYER		1	1		1	1		1	1	1	1	8	4	10
SPACECRAFT/FACTORY SERVICE			1	2	2	3	2	3	5	3	4	25	22	30
FACTORY RESUPPLY		2	3	3	3	4	4	4	5	6	6	40	33	47
CRYSTAL FREE-FLYER		0	0	0	0	1	1	0	0	0	0	2	3	3
		0	0	0	0	1	0							
FACTORY RESUPPLY		0	0	0	0	3	5	7	8	10	14	47	57	67
	MEDIUM	29	29	29	30	37	35	41	50	56	70	407		
TOTALS	LOW	15	16	17	22	22	27	33	39	52	71		314	
	HIGH	31	32	34	41	40	54	58	66	77	91			524

HARDWARE/MASS ELEMENT DEFINITION

Mission Model Six Hardware Elements

The medium mission model 6 is discussed here. In this scenario all commercial MPS payloads were delivered initially to the Space Station. They were then inspected and sent either to the MPS module or to the payload support/ assembly area (PSA). In either case they are processed or checked out and then stored until needed. Subsequent satellite emplacements, and all subsequent satellite servicings, were accomplished with the station-based TMS system.

All Shuttle commercial MPS payloads were named as indicated below, where XX stands for either Space Station or free flyer, and "facility" refers to a complete MPS system.

Payload Name	Actual Listing (Table 3.4-21)
XX Facility	SS MPS Fac FF MDAC Fac FF Xtal Fac
XX Factory Product-N	SS Xtal Fact. Prod. 4
XX Biolab Equipment-N	SS Biolab Equip.
XX Facility Service-N	FF MDAC Fac. Serv 2

The abbreviations SS or FF preceding a name were used to reveal whether the final payload destination was to a Space Station facility or to a free flying facility. "Product" refers to what is produced and always involves an exchange of raw material for finished material. "Equipment" is used only in reference to the SS MPS factory/experiment apparatus. Because of accessibility on the station, the apparatus was continually updated or replaced as required. For MDAC satellites, the entire pharmaceutical factory (11,000 pounds) was replaced (serviced) every four years, representing about 2,750 lb/year. This was designated in Table 3.4-21 as "FF MDAC Fac Serv 2."

The SS Pharmaceutical factory (14,400 pounds) was updated/refurbished with 20 percent of its weight (2,800 pounds) annually. This was referred to as "SS BIOFACT Equip." The pharmaceutical laboratory received 15 percent (750 pounds) of it weight annually. The crystal factory/laboratory together received about 65 percent (1,380 pounds) of the weight annually.

The medium mission model, presented in Table 3.4-21, shows the number of parcels and parcel weights delivered to the station each year along with the total weight/year for each payload.

The number of TMS flights between the station and the satellites are shown in Table 3.4-22. The average TMS payload in transporting crystal products and cartridges is 2,784 pounds each way. This total weight adds up to 311,808 pounds. This corresponds to 37,411 pounds that was brought up and down by the Shuttle and transferred to TMS transporters after loading/ unloading cartridges. The difference of 274,397 pounds that would have to be transported if the Space Station were not in the scenario corresponds to a Shuttle transportation charge of almost $0.5 billion over the 1995-2000 period.

Table 3.4-21. Commercial MPS Medium Mission Model 6 Shuttle Parcel Deliveries/Year (all weight in pounds)

Payload Name	RISD ID No.	Total Weight	Parcel Weight	Calendar Year										Parcels Delivered to Station	Payload Identification Plus Comments
				1991	1992	1993	1994	1995	1996	1997	1998	1999	2000		
SS MPS Module	1320	42,075	42,075	1										1	Loaded with factories/labs
SS Xtal fact.	1328	2,671	2,671					1					1	2	To handle growing market
SS Xtal fact. equip.	1356	630**	210	3	3	3	3	3	3	3	3	3	3	30	Cartridges, etc.
SS Xtal fact. prod. 3	1329	1,994**	500	4	4	4	4							16	GaAs
SS Xtal fact. prod. 4	1332	1,260	420					3	3	5	9	16	24	60	Type III-V Xtals
SS Xtal lab equip.	1327	840	420	2	2	2	2	2	2	2	2	2	2	20	Cartridges, toxicity control
SS Xtal lab prod.	1325	80	40	2	2	2	2	2	2	2	2	2	2	20	Type II-VI Xtals
SS Biofact. resupply	1323	7,700	7,700		1									1	Water tank and water
SS Biofact. equip.	1321	2,820	705		4	4	4	4	4	4	4	4	4	40	Miscellaneous
SS Biofact. prod.	1322	1,200	300		4	4	4	4	4	4	4	4	4	40	Refrigerator (200 lb)/product (10 lb)
SS Biolab equip.	1324	750	250		3	3	3	3	3	3	3	3	3	30	Miscellaneous
SS Biolab prod.	1326	200	100		2	2	2	2	2	2	2	2	2	20	Refrigerator (67 lb/prod. (33 lb)
FF Xtal fac 2	1335	12,572	12,572					1	1					2	Satellite factories
FF Xtal fact serv 3	1345	4,406	4,406					1	1		1			3	Propellant
FF Xtal fac serv 2	1338	800	800							1	1			2	Batteries
FF Xtal fact. prod. 2	1339	2,080	1,040					2	3	5	6	8	12	36	Product
FF Xtal fact. prod. 5	1337	963	963					1	2	2	2	2	2	11	Cartridges
FF MDAC fac	1352	25,000	25,000	1	1		1	1		1	1	1	1	8	Satellite factories
FF MDAC fact. serv 1	1350	6,000	6,000			1	1	1	1	1	2	2	1	10	Factory replacement
FF MDAC fac serv 2	1352	9,000	9,000		1	1	1	2	1	2	3	1	3	15	Facility propellant, etc.
FF MDAC prod.	1348	300	300	2	3	3	3	4	4	4	5	6	6	40	Refrigerated biomedicine
			Totals	29	29	29	30	37	36	41	50	56	70	407	

*Fully loaded with all initial factory/experiment apparatus.
**Includes a 20 percent penalty for container weight

Table 3.4-22. Commercial MPS Medium Mission Model 6 TMS Flights/Year

Destination	Calendar Year										
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Sum
FF Xtal facility-2	-	-	-	-	12	12	16	24	24	24	112
FF MDAC facility	6	9	9	11	14	13	16	19	19	23	139
Total	6	9	9	11	26	25	32	43	43	47	251

Basic Weight Breakdowns

The FF crystal factory in the medium model also served to satisfy the high model by simply adding one more satellite. The weight breakdown is shown in Tables 3.4-23 and -24.

Table 3.4-23. Satellite Crystal Factory Electric Power System--High Model

		kW
Operational Loads		15.000
Furnace	8.0	
Switching regulator	4.3	
Housekeeping	1.0	
Margin	1.7	
Circuit Losses and Charging Power		18.565
Array to load	1.666	
Array to battery	1.611	
Battery charging power	14.499	
Battery to load	0.789	
Array Degradation (5-Year Life)		3.12
Solar Array Output Power		36.687 kW
Solar Array Weight		1,677.00 lb
Size: two wings each		
Battery/Charger/PC Weight:		1,000.00 lb
Total Power System =		2,677.00 lb

Table 3.4-24. Satellite Crystal Factory Subsystem Weights--High Model

Subsystem	Weight (lb)
Solar power system	2,677
Switching regulator and PC	300
Empty four-cycle furnace	2,360
Four-cycle module assembly	2,360
Internal structure, wiring and switches	600
Attitude control and delta V makeup*	550
Thermal control (active and passive)	1,430
Communications	100
Data management	100
Structure	2,095
Total satellite weight	12,572
Total weight without modules	10,212

*This represents the tank and control system weight only. The 4,406 pounds of propellant was added at the station PSA.

The FF MDAC factories were assumed to be mounted on the MMS. The weight estimates in Table 3.4-25 are a best guess.

It was assumed that the module components required replacement or refurbishment every three to six years and that the servicing payloads average 9,000 pounds every three years. Each satellite also required 5,000 pounds of product (mostly water every six months).

The Space-Station-attached MPL module and the factory/laboratory weights have already been given (e.g. Table 3.4-21). The crystal factory design details will be given in a forthcoming IR&D report.

Mission Model 6A

In model 6A the free flyers were retained but the crystal satellite factories were redesigned to operate for six months instead of 30 days so that crystal factory visits could coincide with the MDAC 6-month resupply cycles and shared orbiter flights could become possible. Loaded cartridge weight per six-month mission was about 10,000 pounds per satellite.

The MDAC free flyers in this model are just the way they are planned today and therefore carry the 5,000-pound product resupply penalty twice a year per satellite.

With the assumption that there will be commercial MPS satellites in the 1990's, it must be assumed that R&D flights will also take place for purposes of establishing feasibility of production. NASA, for example, might continue with the joint endeavor agreements which would considerably reduce the large amount of "up front" money. The commercial MPS Mission Model 6A, shown in Table 3.4-26 provides for a limited amount of R&D. There might be early phase mid-deck experiments of a few hundred pounds such as the 600-pounds CFES experiments of MDAC. Subsequent cargo bay experiment, aimed at addressing production feasibility and possibly weighing several thousand pounds, would follow for each sufficiently different production concept. Once MDAC solves its CFES automated production problems, it will be in a position to produce many different biomedicines with little additional R&D unless an entirely different process is found.

It is believed that an average of less than three orbiters can supply the two groups of satellites. However, shared flights were not included in the study.

Table 3.4-25. MDAC/J&J CFES Satellite Weight and Length

SUBSYSTEM	LENGTH[a] (in.)	WEIGHT (lb)
MMS	(150)	(14000)
STRUCTURE & OTHER	33	3010
MODULES		
1 ACS	48	400
4 POWER (INCLUDING 12 BATTERIES)[c]	48	2400
1 C&DH (INCLUDING 2 TAPE RECORDERS)	48	300
1 SC&CU	48	90
1 MK II PROPULSION (DRY)[b]	75	1300
PROPELLANT (N_2H_4)		5500
8 SOLAR ARRAYS	42	1000
CFES	(120)	(11000)
CANISTER (INCLUDING MATERIALS)	48	5000
RADIATOR	120	1000
PLANT	48	5000
TOTAL MPS SATELLITE	270	25000

[a] LENGTHS OF MODULES AND OTHER ITEMS ARE NOT ALL ADDITIVE.

[b] ELECTRONICALLY-STEERABLE SPHERICAL ANTENNA LOCATED ON PROPULSION MODULE.

[c] EACH OF THE POWER MODULES HAS THREE 50-AMPERE HOUR BATTERIES

Table 3.4-26. Commercial Space Processing Mission Model 6A

	Year										Total
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
Pharmaceutical Facility FF											
• Pharmaceutical spacecraft delivery	1	1		1	1		1	1	1	1	8
• Spacecraft service		1	1	1	2	1	2	3	1	3	15
• Factory service			1	1	1	1	1	2	2	1	10
• Factory resupply	5	7	7	8	10	11	12	13	15	18	106
Subtotal	6	9	9	11	14	13	16	19	19	23	139
Crystal factory FF											
• Crystal Spacecraft Delivery					1	1					2
• Spacecraft Service							1	1	1	1	4
• Factory resupply					2	4	4	4	4	4	22
Subtotal					3	5	5	5	5	5	28
R&D subtotal		1		1	1	1	1	1	1	1	8
Total missions	6	10	9	12	18	19	22	25	25	29	175

ECONOMIC VIABILITY

It was found that natural interferon was the most attractive candidate with respect to profit. Based on historical trends, better medicines and improvements in natural interferon (1 of 15 varieties), will take its place and go through a similar cycle of peak in demand, accompanied by a steadily decreasing price per dose. In Rockwell's scenario (Table 3.4-27) the market was predicted to peak in 1994, whereupon it dropped to 25 percent of its valve by the year 2000. This rise and fall was reflected in the cash flow analysis for the pharmaceutical factory. The scenario will be much more profitable because additional products will prevent the dropoff in profit. That is, there are many other promising candidates currently undergoing clinical testing and some will be in demand in the next decade. Also, since the facility was sized to handle over four times the total interferon production, the single product case overestimates costs.

The up-front costs tend to be very high for interferon because of the intrinsic high price and the small increase in effective yield by virtue of MPS.

It is estimated for RIEF that the production of interferon in space will increase the yield by a factor of two and completely eliminate pyrogens (hazardous impurities), which account for the loss of 20 to 30 percent of ground production. In this scenario such improvements suggest that if the last batch (tenth) in the ground production sequence for making interferon is replaced by processing in space, the batch could be three times purer (and therefore capable of providing three times as many doses). In this analysis the concentration is conservatively assumed to be improved by a factor of two and a half. Based on the past history of pharmaceutical sales, the estimated demand and selling price shown in Table 3.4-14 will still remain unchanged from the ground-only scenario.

However, as shown in Table 3.4-27, e.g., in 1994 only 23.2 kilograms of ground-produced product (9 stages of purification) is needed for MPS to produce the equivalent of 58 kilograms of ground-produced product after the last (10th) stage of purification. Table 3.4-27 tabulates interferon production, demand and economics data of the type required to conduct a cash flow analysis. The cash flow analyses for various options are shown in Figure 3.4-27. Please refer to Commercial Utilization of a Space Station: New Business Opportunities. Rockwell International SSD 83-0046 (March 1983).

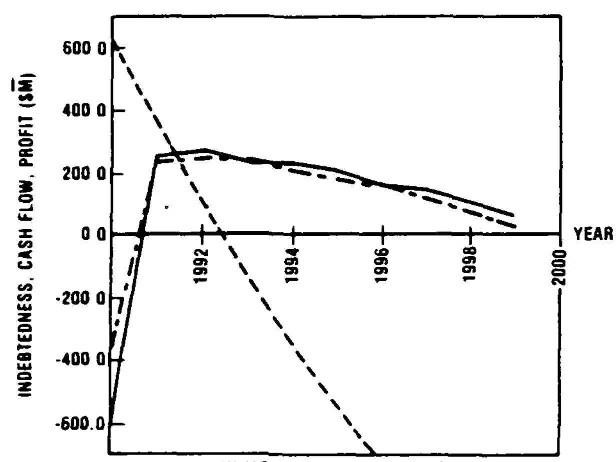
MPS Research and Development

The pharmaceutical industry spends about 11 percent of sales on R&D. A most recent new product required 10 years and 50 million dollars to production and market readiness. These figures reflect large R&D totals, but only a small fraction may be allocated to MPS. (For example, in the case of the recent new product, a straight-line average of $5 million per year was assumed for this study. However, R&D for a new product such as this is a complex, multistep process, most of which takes place on earth.) MPS represents only

Table 3.4-27. Commercial Space Processing Interferon Production Demand/Economics Data

YEAR	WW USER NEED-PURE PRODUCT (KG/YR)	A GROSS VALUE ($M/YR)	B AMOUNT OF RAW PRODUCT* PURCHASED (KG/YR)	C RAW MATERIAL COST $M/YR (0.4A)	D REVENUE (A-C) $M/YR	E PRODUCTION TIME ON ORBIT DAYS (Bx2.2x1.67)	MAN-HOURS PER YEAR* (24x0.21E)	KW/DAYS PER YEAR (4x0.79E)
1991	43.0	817	17.2	326.8	490.2	63	318	199
1992	50.0	850	20.0	340.0	510.0	73	367	230
1993	56.0	896	22.4	358.4	537.6	82	413	259
1994	58.0	870	23.2	348.0	522.0	85	426	269
1995	56.0	784	22.4	313.6	470.4	82	413	259
1996	50.0	700	20.0	280.0	420.0	73	367	230
1997	45.0	630	18.0	252.0	378.0	66	333	208
1998	35.0	490	14.0	196.0	294.0	51	259	161
1999	25.0	350	10.0	140.0	210.0	37	185	117
2000	15.0	210	6.0	84.0	126.0	22	111	70

*TO SATISFY ANNUAL USER NEED FOR ONE PRODUCT.



I BUY MODULE— CHARGE POLICY B

ASSUMPTIONS

- ALL CASES
  - 48% TAX RATE
  - 10 YEAR DEPRECIATION
  - $5.0M / YEAR GROUND OPERATIONS
  - $144.0M FOR FACILITY
  - $18.7M FOR FACILITY LAUNCH
- BUY MODULE
  - $130.0M FOR MODULE
  - $26.0M FOR MODULE LAUNCH
- RENT
  - $80.0M / YEAR (EXCLUDED — POWER, LABOR FACILITY)

CASE	I. BUY MODULE	II BUY MODULE	III. BUY MODULE	IV. RENT MODULE	V. 2X RENT MODULE
CHARGE POLICY	(B)	(A)	(C)	(C)	(C)
M.A.R.R.	15.0%	15.0%	15.0%	15.0%	15.0%
E.R.R.	20.7%	20.8%	20.2%	21.9%	18.0%
NPV	$354 9M	$363.4M	$321 2M	$342.4M	$135.0M
TAXES	$1,384.2M	$1,398.9M	$1,326.3M	$1,271 5M	$859.1M

Figure 3.4-5. Materials Processing Interferon Production Profitability Estimate

one type of step in that process, perhaps separation and purification. Therefore, its value can only be a rather small fraction of the total effort or of each year's effort. Assuming that space-based purification is the beneficial service in the end-to-end research project, it may well be employed three or four times over the life of the 10 year effort, for preparing pure samples for tests with organisms, animals, and humans as the project progresses. The record shows that the value of pure samples can be considerable. Therefore, it appears reasonable to assume that the MPS market would capture $3-4 million of each such project. Given the 10-year lead time and a substantial number of competitors, there is a rather large number of parallel and overlapping projects and potential for a significant MPS market in the biological-pharmaceutical area. Furthermore, purification-separation represents an essential but elementary step; MPS in this segment should increase as more complex research involving multistep processes in space are carried out.

However, one must be careful of over-optimistic projections. Competition for the research dollar will be keen, and traditionally the market has shown little elasticity as a function of price. Lower costs may broaden the market's base but may not generate substantial additional MPS experimentation.

Although the R&D market for low gravity research is promising, the return on investment is low because of the need for a diverse base of expensive space certified hardware that may not be used frequently enough to provide a satisfactory payback. IF the R&D market is to be viable, government support will probably be needed in addition to industrial and venture capital. As an alternative, firms engaged in providing R&D services for MPS should also provide production facilities for rent. This provides two benefits, the R&D supplier is ensured a very good rate of return and the firms seeking to produce materials save considerable capital expenditures.

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3.5 COMMERCIAL COMMUNICATIONS

Our objective in the commercial communications areas has been twofold:

- To explain to selected representatives of the industry the attributes of the Space Station as it will affect them in the future.
- To understand their concerns, interests, preferences and requirements so that we may incorporate them into our study.

The industry representatives that have been our main contacts during the study are:

- Bell Laboratories, Inc.
  Crawfords Corner Road
  Holmdel, New Jersey 07733
- British Aerospace Public Limited Company
  Dynamics Group
  Space and Communications Division
  Gunnels Wood Road
  Stevenage, Hertfordshire SG1 2AS
  United Kingdom
- Hughes Aircraft Company
  Space and Communications Group
  P.O. Box 92919
  Los Angeles, California 90009
- International Telecommunications Satellite Organization (Intelsat)
  490 L'Enfant Plaza S.W.
  Washington, D.C. 20024
- RCA
  Research and Engineering
  David Sarnoff Research Center
  Princeton, New Jersey 08540

We have also used, on a subcontractor basis, the services of Mr. Walter Morgan, Communications Center of Clarksburg, 2723 Green Valley Road, Clarksburg, Maryland 20871

In addition, we have held discussions related to the Space Station with the following firms and agencies:

- AT&T Long Lines
- Comsat General Corporation

- Direct Broadcast Satellite Corporation
- Econ Incorporated
- Federal Communications Commission
- GTE Satellite Corporation
- Harvard University Graduate School of Education
- NASA Lewis Research Center
- National Telecommunications and Information Administration
- Public Service Satellite Consortium
- Satellite Systems Engineering, Inc.
- Satellite Television Corporation
- Western Union

In what follows we present results of specific analyses and studies. While we have integrated inputs from our contacts in these results, there are no specific attributions made to any named user and we have not incorporated any proprietary data given to us. The results, however, generally reflect concerns and viewpoints obtained from these contacts.

HISTORIFORECAST, 1960-2010

Figure 3.5-1, which we call a "historiforecast," covers 50 years of communications satellite launches in the free world. The forecast from 1984 through 2010 is based on our nominal model and includes free world satellites to be launched by U.S. and foreign launch systems.

The periodicity of 10-year periods post-1980 is due to our assumption of a 10-year replacement cycle. Real life variations of satellite life times will tend to even out these peaks and valleys.

COMMERCIAL COMMUNICATIONS MODEL CONSTRUCTION

Nominal Forecast, 1990-2000

We have made a forecast of free world commercial communications satellites to be launched between 1990 and 2000. This forecast is based on an extrapolation of past and currently planned satellite systems, based on data in the public domain. We have used no specific or proprietary data given to us by our user contacts, but have relied heavily on their viewpoints, preferences, and requirements to mold our forecasts.

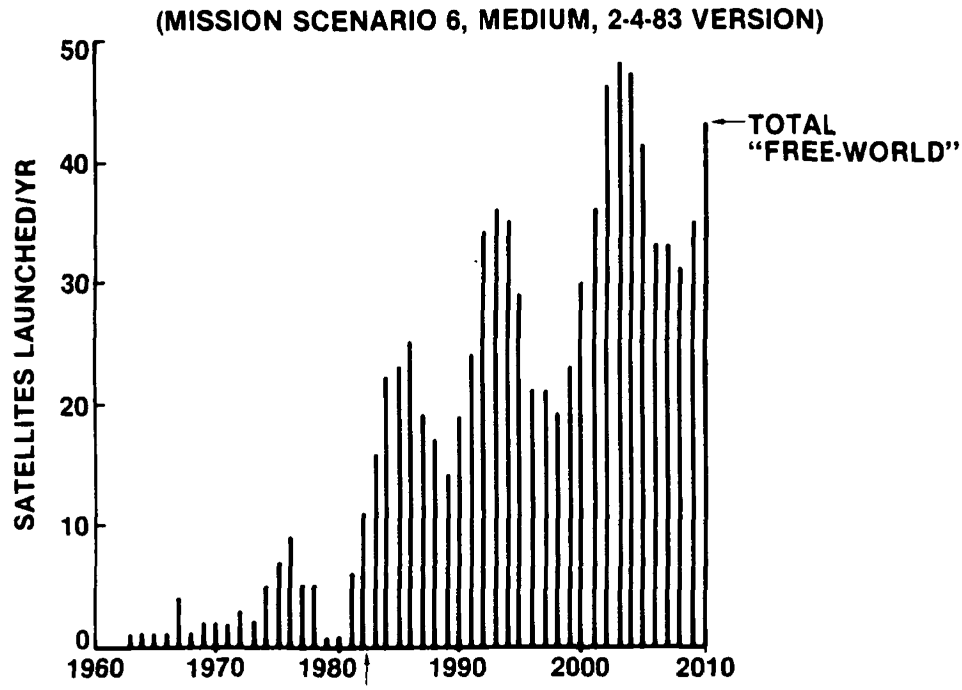


Figure 3.5-1. A 50-Year Historiforecast of Comm Sats (Mission Scenario 6, Medium, 2-4-83 Version)

The basic assumptions for creating our model are:

- Current users will continue operations through 2000, replacing satellite by satellite.

- Most of the currently planned new satellite systems will become operational, but sometimes later than currently planned.

- Satellites will be replaced every 10 years. Replacement satellites will generally be 20 percent more massive than the ones they replace.

- Starting in 1989, four new users (not now identifiable) will come into being every year through 2000. Each will launch three satellites at the rate of one per year. These will have an average mass of 3000 pounds in 1990, growing to 4000 pounds by 2000, with variations of $\pm$1000 pounds.

- Starting in 1995, multi-user systems (MUS) will come into being. These will combine communications payloads belonging to two to four separate users onto large satellite buses provided by third parties. MUS's will be assembled at the Space Station and delivered from there to geosynchronous orbit. One MUS per year will be used, replacing two to four satellites each. MUS masses will be 7500 to 9000 pounds.

- Although the technology will be available, larger "platforms" or "orbital antenna farms" will not occur until after 2000.

The total number of satellites launched per year is shown in Figure 3.5-2 broken down into three mass categories.

The complete list of these spacecraft is shown in the section on Shuttle Space Station and OTV Capture.

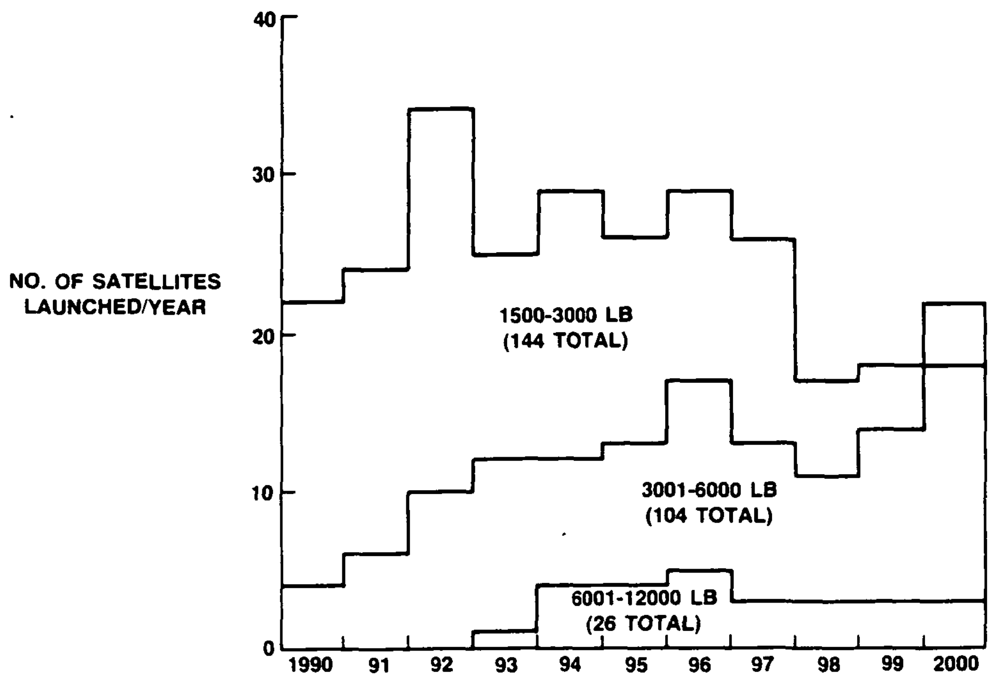


Figure 3.5-2. Commercial Communication Satellites, Free-World Launches by Satellite Size in GEO Circular Orbit

Shuttle, Space Station, and OTV Capture

We have made a forecast of which satellites in our nominal model will be captured by:

- Expendable launch vehicles
- Shuttle/expendable upper stages
- Shuttle/Space Station/OTV

These are listed, by name, in Tables 3.5-1, -2, and -3. Although we have shown specific users in these lists, and have similarly omitted other potential users (e.g., some DBS applicants), we are not implying any special knowledge on the viability or otherwise of specific users. Inclusions and omissions between competing systems should be regarded as based on chance rather than inside knowledge.

Table 3.5-1. *Expendable Launch Vehicle Users*

Name	Mass (lb)	No. Launched	Year of First Launch
Anik E	2000	1	91
Anik F	2000	3	91
Arabsat F/O	2500	2	92
Eutelsat F/O	2800	5	90
Helvetsat F/O	2000	2	94
Insat-F/O	2500	2	90
Insat-F/O-2	3000	2	99
Intelsat VI	3918	1	90
Intelsat VIA	4300	3	91
Intelsat VII	7500	7	94
Intelsat F/O	2000	2	94
Marecs F/O	2600	3	91
Mexsat	2000	1	90
Palapa F/O-2	2500	3	90
TDF-F/O	2000	2	92
Telecom F/O	2300	2	91
TV-Sat-F/O	2500	2	92
89-2	2900	2	90
89-2-F/O	4100	2	99
89-4	2400	2	90
89-4-F/O	3400	2	99
90-2	4000	3	90
90-2-F/O	5600	1	00
90-4	3000	3	90
90-4-F/O	4200	1	00
91-2	2100	3	91
91-4	3600	3	91
92-2	3200	3	92
92-4	3200	3	92
93-2	2800	3	93
93-4	4300	3	93

Table 3.5-1. Expendable Launch Vehicle Users (Cont)

Name	Mass (lb)	No. Launched	Year of First Launch
94-2	3400	3	94
94-4	2400	3	94
95-2	4000	3	95
95-4	3500	3	95
96-2	3600	3	96
96-4	3100	3	96
97-2	4700	3	97
97-4	3700	3	97
98-2	2800	3	98
98-4	4300	3	98
99-2	3900	2	99
99-4	3900	2	99
00-2	3500	1	00
00-4	5000	1	00
		116	

The terminology used is as follows.

- Current system names are used for known systems. The term F/O means follow on (replacement) system; and F/O-2 means the next generation follow on.
- New (unknown) systems are identified by two numbers, representing the year of first launch, and a user serial number for that year (e.g., 93-3 identifies the third user whose first satellite is launched in 1993).
- MUS stands for multi-user system. Each MUS may have different users' payloads on it.

We have also made estimates of how many, and which, spacecraft will wish to use the following additional Space Station related services:

- Satellite checkout in low earth orbit (LEO).

Table 3.5-2. *Shuttle/Expendable Upper Stage*

Name	Mass (lb)	No. Launched	Year of First Launch
Amersat F/O	1875	3	93
Aussat F/O	2000	2	92
Brasilsat F/O	1700	3	92
CBS-DBS	2000	4	90
Galaxy, F/O	1600	3	90
Intelsat VI	3918	2	90
Intelsat VIA	4300	2	92
Palapa F/02	2500	3	90
RCA Satcom F/O	1550	2	90
RCA Satcom K-F/O	2000	4	92
SBS F/O	1550	3	90
STC DBS-F/O	1770	4	92
Telstar 3-F/O	2100	3	93
Westar F/O	1800	5	92
89-1	2900	2	90
89-3	2400	2	90
90-3	3000	3	90
		50	

- Deployment of solar arrays, antennas, and other appendages in LEO before transfer to geosynchronous orbit.
- Periodic servicing by specialized automated teleoperator maneuvering systems in geosynchronous orbit.

These are indicated by check marks in Table 3.5-3, Shuttle/Space Station/ OTV Users list.

Considerations of user preference, national interests, institutional issues, costs, and the relative attractiveness of Shuttle, OTV, and the services offered at the Space Station, have entered into these decisions.

The following assumptions were used as a basis in the analysis:

- By 1990, the only U.S. government-provided or -sponsored launched system will be the Space Shuttle.

Table 3.5-3. Shuttle/Space Station/OTV Users

Name	Mass (lb)	No. Launched	Year of First Launch	C/O	Deployment	Geoserviceable
Anik G	2,000	1	99			
CBS-DBS-F/O	2,800	1	00			
DBSC F/O	4,000	3	96		✓	✓
Fordsat F/O	3,150	2	96		✓	✓
G-Star F/O	1,900	4	92		✓	
Intelsat VII	7,500	7	94		✓	✓
L-Sat F/O	7,280	2	94		✓	
Luxsat F/O	2,500	2	95			
Mexsat F/O	2,500	2	99			
M-Sat F/O	3,500	1	95		✓	
Nordsat Telex F/O	4,410	3	93		✓	
Oaksat F/O	2,000	3	96		✓	
RCA Satcom F/O2	2,170	5	96		✓	✓
Satcol F/O	1,875	2	96			
SBS F/O-2	2,170	3	97			
Spacenet F/O	1,540	4	94		✓	
TDRS F/O	7,500	4	93	✓	✓	✓
Telesat DBS-F/O	3,000	2	96		✓	
Telstar 4-F/O	2,100	3	97		✓	
Unisat F/O	2,000	2	96			
USSAT F/O	4,000	2	95			
Westar DBS F/O	2,700	4	97	✓	✓	
Westar K-F/O	2,400	3	96			
89-1-F/O	4,100	2	99			
89-3-F/O	3,400	2	99			

Table 3.5-3. Shuttle/Space Station/OTV Users (Cont)

Name	Mass (lb)	No. Launched	Year of First Launch	C/O	Deployment	Geoserviceable
90-1	4,000	3	90			
90-1-F/O	5,600	1	00			
90-3-F/O	4,200	1	00			
91-1	2,100	3	91			
91-3	3,600	3	91			
92-1	3,200	3	92		✓	
92-3	3,200	3	92			
93-1	2,800	3	93	✓	✓	
93-3	4,300	3	93			
94-1	3,400	3	94			
94-3	2,400	3	94		✓	
96-1	3,600	3	96	✓	✓	✓
96-3	3,100	3	96		✓	
99-1	3,900	2	99		✓	
99-3	3,900	2	99		✓	
MUS-I	9,000	2	95	✓	✓	✓
MUS-II	12,000	4	97	✓	✓	✓
		114				

- Other launch systems, particularly the Ariane, will be available and competitive.
- U.S. and some foreign satellites will mostly use the Shuttle.
- 50 percent of the new (unknown) systems will use Shuttle and 50 percent the Ariane and other ELV's.
- The Ariane will be the choice of French, German, and European Space Agency systems.

- Intelsat satellites will be launched on a 50-50 basis by Shuttle and by other systems.
- The Space Station will become operational in 1991, but will not be used by communications satellites until 1994, when the OTV becomes operational.
- Relatively few users (one out of 20 in the early 90's) will require satellite checkout at the Space Station.
- Deployment of appendages, and consequent low-thrust acceleration (0.1 g) on OTV to geosynchronous orbit, will be relatively popular for Space Station/OTV users (one out of four in the early 90's to one out of two in the late 90's).
- Assembly will only be required by the multi-user systems.
- Geoservicing of satellites will become very attractive, mainly for updating payloads (e.g., adding services, replacing old technology by new), and for adding propellants. Geoservicing will start on a few large systems in 1996 and will expand rapidly through 2000. Geoservicing will typically be done every three or four years on a geoserviceable satellite.

Results of this analysis are summarized in Figure 3.5-3. These show the number of satellites launched by the different systems and the number using the various services.

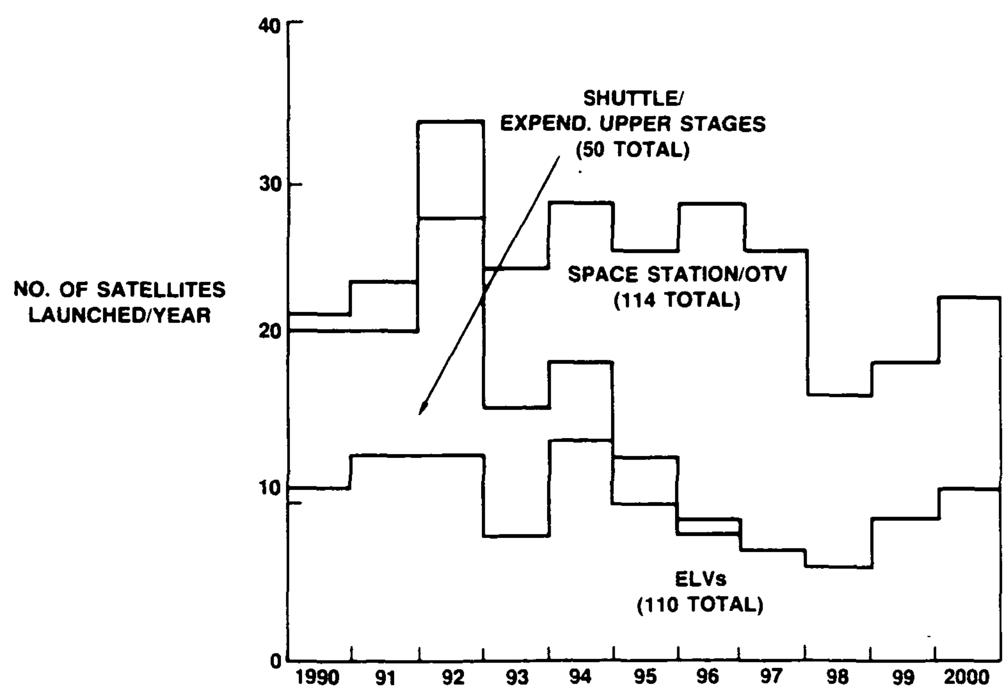


Figure 3.5-3. Commercial Communication Satellites, Free-World Launches by Launch Mode

Low and High Forecasts, 1990-2000

We developed low and high forecasts in order to understand possible variations. These have been interpreted as follows:

- Low - 80-percent probability that the traffic will be at least this much.
- Medium or nominal - 50-percent probability that the traffic will be at least this much.
- High - 20-percent probability that the traffic will be more.

The basic differences from our nominal model are:

Low

- Slightly fewer known users and a few launches occur later.
- Two or three new (unindentified) users per year, each with three satellites, starting in 1989.
- Fewer users select Shuttle, and a smaller proportion of these use Space Station and OTV.
- Multi-user systems do not occur before 2000. The missions are done instead by individual satellites.
- Geoservicing does not occur before 2000.
- No use is made of satellite checkout at Space Station, and deployment is reduced to one out of six Space Station/OTV users.

High

- A few more known users and a few launches occur earlier.
- Six new (unidentified) users per year, each with four satellites, starting in 1989.
- More users select Shuttle, and all of these use Space Station and OTV (from 1994).
- There are nine multi-user systems between 1996 and 2000 instead of six (still with a maximum of four payloads per system).
- Checkout at Space Station and geoservicing is used by more satellites, and deployment of appendages before transfer to geosynchronous orbit becomes the rule by the late 1990's.

The number of spacecraft launched through Shuttle and Station are compared in Figures 3.5-4 and -5. We have not worked out low and high models for the non-Shuttle launched spacecraft.

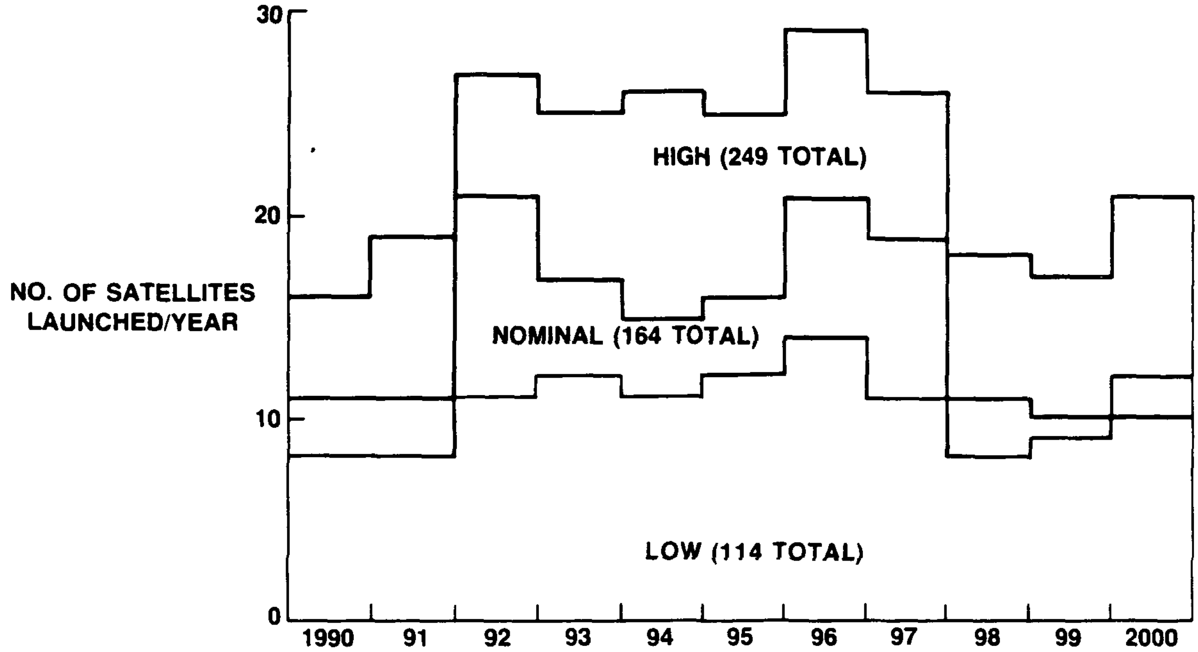


Figure 3.5-4. Communication Satellites Captured by Shuttle

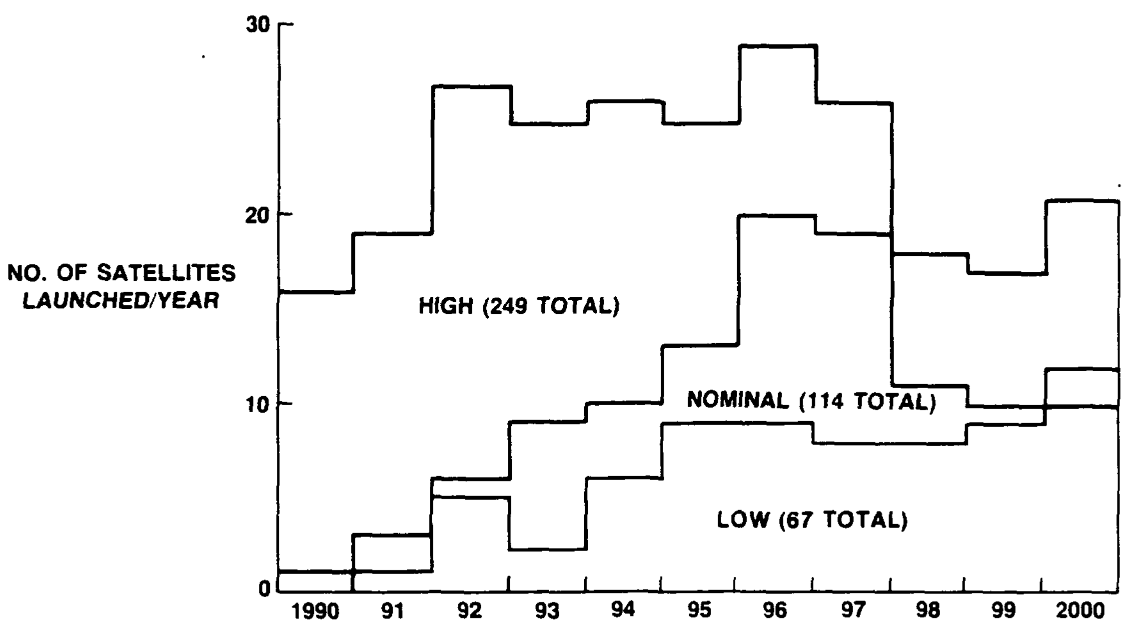


Figure 3.5-5. Commercial Communication Satellites Captured by Space Station/OTV

SPACECRAFT SIZE AND DESIGN CONFIGURATION

Experience with the Shuttle has shown that dimensions of Shuttle payloads are strongly influenced by the applicable charge policy. The current Shuttle charge policy has led to so-called Shuttle-optimized designs, in which the length and weight are in the ratio of 60 feet to 65,000 pounds.

We do not know what the Shuttle charge policy will be in the late 1990's. However, based on our analyses of the factors enumerated in the following,

- The expected traffic
- Increasing the average mass load factor on the Shuttle by carrying high density propellants (i.e., high density relative to spacecraft)
- The use of the reusable space-based orbital transfer vehicle, which removes the need for each spacecraft to provide its own perigee propulsion
- Practical design considerations for spacecraft
- An acceptable pricing policy regarding Shuttle payload lengths

we are recommending the following specifications for Space Station optimized spacecraft:

- Diameter: 14 to 14.5 feet
- Length in the Shuttle: 2 + .001W feet where W is the spacecraft weight in the Shuttle (i.e., payload + bus + apogee propulsion system, including apogee propellants), in pounds
- Direct attachment to the orbiter (i.e., no cradle)
- Attachment provisions to the OTV (TBD)
- Designed for deployment of appendages at the Space Station (if desired). Volumes and envelopes allowed are TBD
- Built-in apogee propulsion system with a maximum thrust to weight ratio of 0.1
- Payload and spacecraft reconfigurable at Space Station (if desired) for 0.1 g maximum acceleration on the OTV.
- Designed (if desired) for unmanned automated servicing of propellants, payload, and subsystems at geosynchronous orbit.

The length relationship to spacecraft weight in the orbiter (which is equal to the weight in geo transfer orbit) and to the weight in circularized geo orbit is shown in Figure 3.5-6.

It will be noticed that we are recommending larger diameters and shorter lengths than are currently being used.

The attached provisions to the OTV need not result in any significant weight or length penalties. An attractive solution would be the use of the remote attach mechanism used in the flight support system of the NASA MMS (Multi-Mission Modular Spacecraft). It has a three-point mechanical attachment system, one or two optional electrical umbilical connectors, and will be well proven by the early 1990's.

ORBITAL TRANSFER VEHICLE

We have analyzed a variety of transportation modes from low earth orbit to geosynchronous and other high energy orbits (e.g., for planetary missions). We have concluded that, considering all the missions that need to be performed in the 1990-2000 year period, the best solution for the USA is an orbital transfer vehicle (OTV) with the following characteristics:

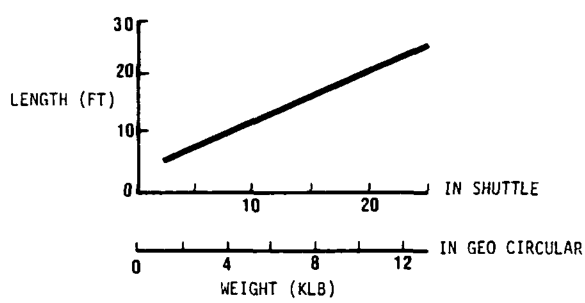
- Cryogenic propellants (LO_2/LH_2)
- Space-based at the Space Station
- Reusable about 40 times, with refurbishment (on earth) after twenty missions
- Low thrust (0.1 g max acceleration)
- Normally used as a perigee stage, inserting communications satellites into geo transfer orbit and then returning to the Space Station orbit.
- Sized for inserting 24,000 pounds into geo transfer orbit (i.e., approximately 12,000 pounds into geo circular orbit)
- Normal communications satellite missions will be to deliver one satellite of 6,000-12,000 pounds, two satellites of 3,000-6,000 pounds, or three satellites of 1,500-3,000 pounds *to geo transfer orbit* (the weights quoted are in geo circular orbit; the satellites provide their own apogee propulsion).
- Servicing the OTV, including loading of propellants from storage tanks and attaching spacecraft, is done at the Space Station under the control of the Space Station crew

We have selected this OTV concept because it best satisfies the overall traffic we have predicted, provides lower costs than current or potential alternatives, off-loads effficiently for payloads less than its maximum design point, and offers considerable flexibility in use (e.g., as an expendable stage, as a perigee/apogee OTV, staged with a second OTV or with other kick stages, or with added tankage). Its normal operational mode is shown in Figure 3.5-7.

Cost breakdowns and comparisons with some alternative systems are shown in Figure 3.5-8 and Table 3.5-4 for satellites of 1,400 pounds, 5,000 pounds, and 12,000 pounds.

- **DIAMETER: 14 TO 14.5 FT**
- **LENGTH IN SHUTTLE: $2 + \frac{W}{1000}$ FT**

(W = WEIGHT IN SHUTTLE, INCL APOGEE PROPULSION + ASE, IN LB)



- **DIRECT ATTACHMENT TO ORBITER (i.e., NO CRADLE)**
- **ATTACHMENT PROVISIONS TO OTV (MECHANICAL, ELECTRICAL)**
- **BUILT-IN LIQUID APOGEE PROPULSION — 0.1 g**
- **OPTIONS:**
  - **DEPLOYMENT OF APPENDAGES AT STATION — 0.1 g**
  - **CHECK-OUT AT STATION**
  - **SERVICING (UNMANNED) IN GEO ORBIT**
- **1994 FIRST OPERATIONAL AVAILABILITY**

Figure 3.5-6. Design Guidelines for Space-Station/OTV-Optimized Communication Satellites

GEOSYNCHRONOUS SERVICING, MULTI-USER SYSTEMS, AND PLATFORMS

We have concluded that these three issues are interconnected and that the Space Station will catalyze an earlier realization of these. Our medium scenario has the following activities in these three areas.

Starting in 1995, multi-user systems (MUS's) will come into existence. These consist of a large spacecraft bus, which provides a structure, electrical power, pointing, attitude control, stationkeeping, thermal control, propulsion, mechanical support, and possibly antennas. Each of two to four individual users provides, as separate packages, his own communications payloads containing transponders, antennas, and controls. The spacecraft bus and the individual communications payloads may be taken up to the Space Station on the same or on separate Shuttle flights, depending on the owner's convenience, and are assembled at the Space Station into a single multi-user-system. This is in turn

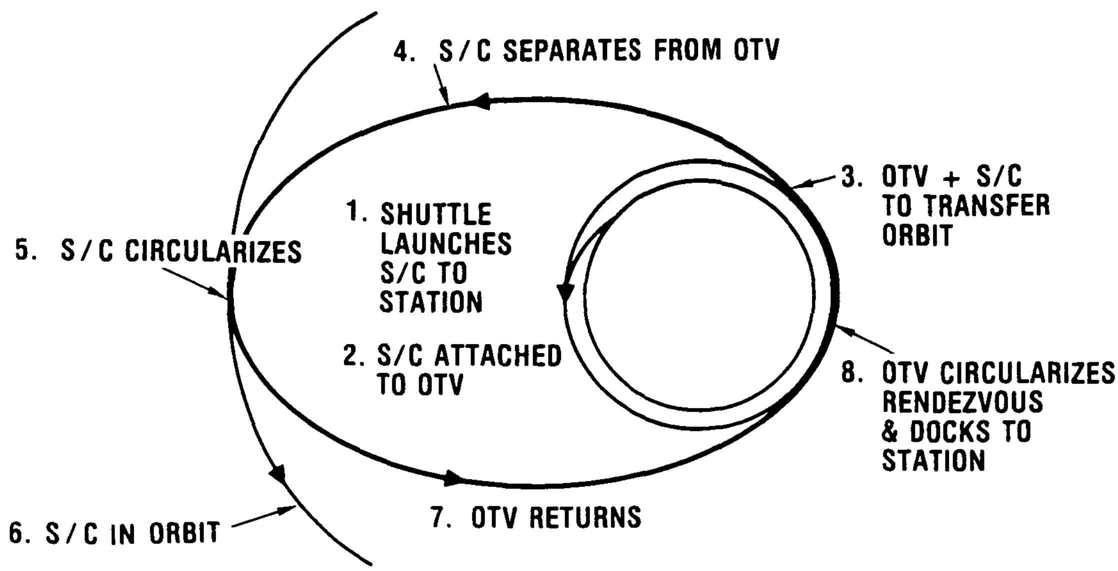


Figure 3.5-7. Reusable OTV Mission Mode

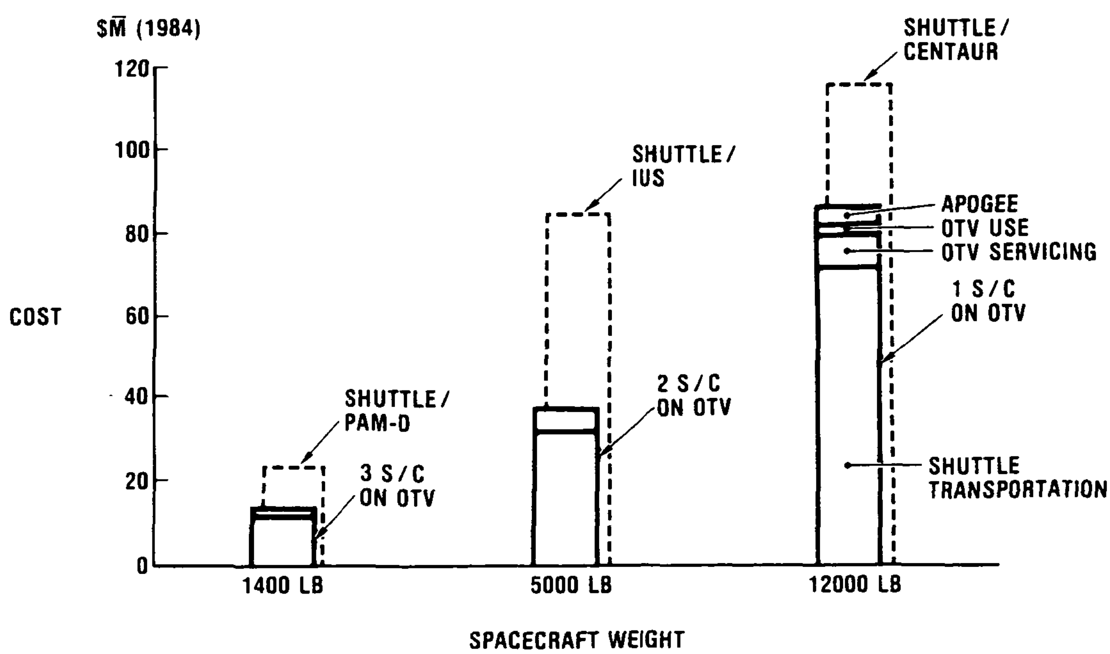


Figure 3.5-8. Transportation Costs to GEO

Table 3.5-4. Communications Satellite Cost Detail

	PAM D CLASS (1400 LB)				IUS-1 CLASS (5000 LB)			CENTAUR-F CLASS (12,000 LB)	
	STS	SS (1)	SS (2)	SS (3)	STS	SS (1)	SS (2)	STS	SS
S/C WT (KLB)	1 40	1 40	2 80	4 20	5 00	5 00	10 50	12 00	12 00
OTHER WT (KLB)	8 60	12 50	17 30	22 10	38 00	22 80	37 40	51 00	41 20
TOTAL WT (KLB)	10 00	13 90	20 10	26 30	43.00	27 80	47 90	63 00	53 20
LEO TRANS COST ($/LB)	1,642 00	1,354 00	1,354 00	1,354 00	1,642	1,354 00	1,354 00	–	1,354 00
TRANS COST – ($M̄)	16 42	18 80	27 20	35 60	70 60	37 60	64 80	77 00	72 00
PERIGEE STG COST – ($M̄)	6 35	–	–	–	12 50	–	–	39 00	–
AKM COST ($M̄)	0 50	0.50	1 00	1 50	1 50	1 5	–	3.00	5 00
OTV USE COST ($M̄)	–	1 35	1 35	1 35	–	1 35	1 35	–	1 35
OTV SERVICE COST ($M̄)	–	2 40	2.70	3 00	–	3 38	6 45	–	7 70
TOTAL COST ($M̄)	23 30	23 00	32 20	41 40	84 60	43 80	75 60	116 00	86 00
$/LB TO GEO	16,600 00	16,500 00	11,500 00	9,900 00	16,900 00	8,800 00	7,600 00	9,700 00	7,200 00

assembled onto an OTV and delivered, with antennas, solar arrays, and other appendages deployed and checked out, to geosynchronous orbit.

Although we have not done any design studies, we see a number of potential advantages in the MUS:

- It allows the communications firms to concentrate on what they know best, namely communications equipment, rather than spacecraft
- Commonality of bus services will result in economies of scale
- More flexibility in launching the bus and its payloads to low earth orbit and the ability to do some on-orbit testing, without delaying the use of a lot of other equipment.

We have concluded that commercial multi-user systems will only happen if, more or less simultaneously, an economical means for servicing satellites in geosynchronous orbit is available. In our model we introduce this geoservicing capability in 1996. The concept is that geoservicing is provided by two automated (i.e., unmanned) satellites. These satellites have the normal spacecraft functions (power, thermal control, TT&C, etc.), but their payloads are devices needed for servicing satellites. These devices are seen, in our scenario, as developments from the teleoperator maneuvering system (TMS)--namely, manipulator arms, mating devices, propellant tanks and propellant transfer systems, TV cameras, storage racks, diagnostic devices, etc. These satellites have enough on-board propulsion so that, once in geo orbit, they can in turn visit any of

the satellites in geo orbit that want servicing over a period of, say, six months. We have concluded, from our user contacts, that the main purposes of geoservicing communications satellites will be to:

- Add new payloads
- Update (e.g., replace) out-dated payloads
- Add stationkeeping propellants

with a much lower priority use being:

- Repair failed spacecraft or payload components

While these servicing satellites have certain basic capabilities, equipment and standard consumables (i.e., propellants) on board, or special equipment such as additional or replacement payloads, have to be delivered separately. This equipment and these supplies have to be delivered to geo orbit whenever required, either in an integrated "geoservicing payload" as an OTV payload, or piggy-backed on some other geo payload. Once a payload is delivered to geo orbit, the geoservicing satellite will rendezvous with it, pick it up and deliver it to the user satellite.

The scenario just described has a number of advantages:

- Satellites are serviced in their orbit without need to be brought to low earth orbit or to earth or even to change their orbital location
- "Standard" services such as replenishment of stationkeeping propellants can be provided without the satellite owner having to launch anything.
- Updating of satellites can be done by launching, or arranging to be launched, only the extra equipment needed rather than a new satellite.
- Payloads or equipment which are late, or which are only needed later, can be added later, thus saving the capital investment in years when they are not needed.

As shown in Figure 3.5-9, our analysis shows that the first geoservicing satellite (called the GEO TMS) should have its initial operational capability (IOC) in 1993, with two to three years of testing on a NASA satellite. The full operational capability (FOC) is shown in 1995, and our first commercial use is scheduled in 1996. In order for confidence to be gained, the announcement of a geoservicing capability should be made (by NASA, or by a commercial developer) in 1985, thus allowing the award of the first geoserviceable geo satellite contract in 1987, with the decision by the owner to rely on geoservicing made in 1990. Our schedule also shows low earth orbit servicing missions expected in the 1980's, all of which provide confidence in the concept of servicing.

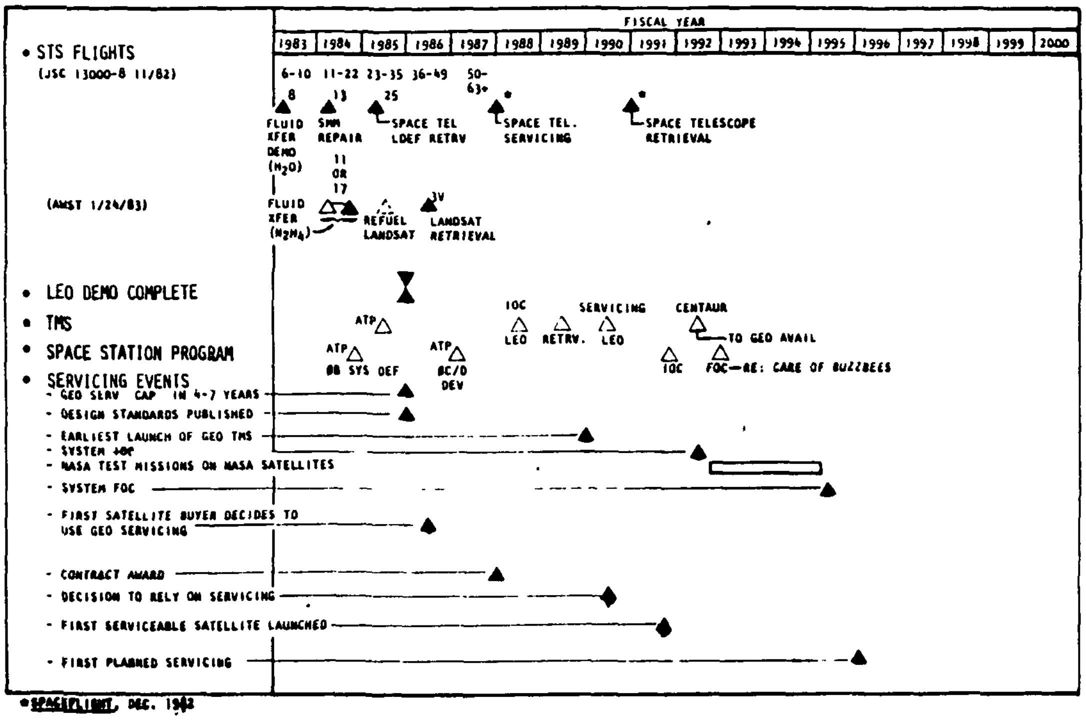


Figure 3.5-9. Development of GEO Servicing Capability

We have also concluded that, without a Space Station, geoservicing will be delayed to beyond the year 2000. The reason is that the Space Station provides many opportunities to test servicing in low earth orbit (e.g., in servicing co-orbiting space processing satellites), and to develop the techniques, operations and equipment; and this will therefore allow for early development of the corresponding geo capability. The same developments will occur without a Space Station, with only the Shuttle; but because of the much smaller number of low earth orbit serviceable satellites, geoservicing will be delayed to beyond 2000.

The third item in our scenario is the development of large platforms. In our scenario these do not appear on the scene until early in the next century, but they are spurred by the experience gained by the multi user-systems and geoservicing. Without the Space Station all three of these items are thus delayed by many years.

Our concept of the platform, which has been developed in conjunction with some of our user contacts, is an extension of the multi user system on a larger scale. The platform itself is a large spacecraft (perhaps of many tens of thousands of pounds in mass) which is assembled from smaller components at the Space Station and taken up to geo orbit at a low acceleration, with or without some payloads. Like a multi-function building on earth, it invites and gradually accumulates a number of tenants, with a variety of missions: communications, environmental monitoring, observations, weather, etc. Payload equipment can be added or removed by using standardized "slots," modules and interfaces. The availability of geoservicing makes both the platform and its tenants'

equipment serviceable, with a potentially very long life (e.g., 25 years for the platform). As in the case of a building, excess capability in the early years, before it is filled up, can be rented out; e.g., excess power can be beamed (by laser) to adjacent satellites.

We believe that the availability of such platforms, soon after the year 2000, will revolutionize the design and the economics of space hardware in the geosynchronous area. Space users will be able to concentrate on their mission equipment, they will be able to think of low cost repairable/replaceable/expendable equipment, and will be able to spread out their capital investments to satisfy their experienced customer demand rather than having to invest for a projected demand 10 years ahead.

3.6 NATIONAL SECURITY

The mission model for the National Security user is presented in the DOD task volume. However, the mission summary totals by year is included on previous Tables 2-1 and 2-2 (Section 2) for Mission Scenarios 6 and 6A, respectively.

3.7 TECHNOLOGY DEVELOPMENT

GENERAL APPROACH

Rockwell's approach to structuring the Technology Development (TD) mission model for Mission Scenario 6 is based on identifying six new, major, future space initiatives in order to derive those technology missions which would benefit by using the Space Station as a national resource. For this reason, space initiatives were chosen which would provide a broad, but representative, set of development/demonstration missions. Technology development in support of national defense initiatives is included in the DOD mission model (Task 4.0). Also, initiatives which appeared to be controversial (such as the Solar Power System) were avoided in order to foster credibility of the TD mission model. Finally, the focus of the TD mission model was not on the basic subsystem level of research and development (normally demonstrated with simulated environments on the ground), but concentrated on those major system-level demonstrations which require the actual space environment for complete resolution. The space initiatives chosen are listed below.

Space Initiative	Operational Date
• Geosynchronous Multi-function Communications Platform	2001
• Large Astronomical Observatory	2002
• Global Environment Monitoring System	2003
• Earth Orbiting Micro-Gravity Facility	2004
• Lunar Operations Base	2006
• Manned Mars Mission	2008

The next step involved a Rockwell panel composed of experts in a range of disciplines (communications/tracking, propulsion, environmental/life support, thermal control, propellant storage/transfer, guidance and control, and large space structures). The panel assessed each space initiative for the key areas of technology development/improvement (above and beyond current state of the art) needed to implement such a program. This effort produced a total of 84 technology issues. Table 3.7-1 summarizes the 84 technology issues by discipline and by space initiative. Two additional issues were added which are representative of support to the initial Space Station operations.

Further review identified 24 issues which did not require on-orbit development. The remaining 62 were then combined to form 26 viable TD missions. This step appeared to be necessary (as a cost saver) where one mission could resolve one or more of the issues.

Table 3.7-1. Summary of Technology Issues

Selected Program \ Technology Areas	Guidance and Control	Large Space Structures	Primary Power	Secondary Power	Power conditioning and Distribution	Electrical Components	Propulsion	Thermal Control	Communication	Electromagnetic	Servicing	Sensors	Materials	Life Science	Total
Geosynchronous Multi-Function Comm. Platform	5	2	1	1	1	3	1	1	3	1	1				20
Large Astronomical Observatory	6	2					1		2			1			12
Global Environment Monitoring System	5	2	1				1	2	3	1	1				17
Earth Orbiting Micro-Gravity Facility	3						1		1			2	2	2	11
Lunar Operations Base			1			2			1			4	1	2	11
Manned Mars Mission	1	1	2				1		1			4	1	2	13
	20	7	5	1	1	5	5	3	11	2	2	11	6	5	84

Each mission supports one or more technology discipline, as shown below.

- Fluid storage/transportation (one mission)
- Communication/tracking (three missions)
- Large space structure (four missions)
- Guidance and control (five missions)
- Primary power (two missions)
- Thermal control (two missions)

- LEO/GEO servicing (one mission)
- Auxiliary propulsion (one mission)
- Space processing (three missions)
- Crew safety (three missions)
- Environmental/life support (one mission)

Table 3.7-2 identifies each TD mission by name and year of launch for the medium mission model. The low and high mission models are summarized by the number of launches per year.

Table 3.7-2. TD Mission Summary for Scenario 6

Payload/Mission Name	Year										
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Total
Laser comm and tracking demo	1										1
Fluid storage/ transfer		1									1
Deploy/retract lightweight structure		1									1
Assemble large space structure			1								1
Config control large space structure				1							1
Lightweight high voltage solar array				1							1
Multi-kW heat pipe performance					1						1
Spacecraft refurb demo			1								1
Data bus noise suppression				1							1
Controlled accel thruster					1						1
Large telescope assy and alignment							1				1

Table 3.7-2. TD Mission Summary for Scenario 6 (Cont)

Payload/Mission Name	Year 1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Total
<0.1 microradian telescope pointing								1			1
Long life cryo refrig demo					1						1
Narrow beam antenna							1				1
Platform pointing/ stabilization							1				1
Large flexible structure shape control								1			1
Ultra-precise low gravity sensor									1		1
Auto grow/feed life forms										1	1
Portable solar flare warning										1	1
Medium model total	1	2	2	3	3	-	3	2	1	2	19
Low model total	1	2	1	2	3	1	2	2	1	-	15
High model total	1	2	3	3	2	1	4	3	2	1	22

MODEL CONSTRUCTION PROCESS (1991-2000)

The high TD mission model was constructed by supporting all future, major space initiatives based on a reasonable implementation schedule. Each mission was scheduled in such a way that, collectively, all missions supporting a specific space initiative would be completed in time to affect the design and/or operation of the end product (operational dates previously shown). The basis of this approach is the assumption that the national economy has fully recovered and the high adventure of science and space exploration permits the necessary funding levels.

Medium Model

The medium TD mission model was constructed by delaying the resolution of technology issues for the following space initiatives and rescheduling their initial operational dates.

- Large Astronomical Observatory (2003)
- Earth Orbiting Micro-Gravity Facility (2006)
- Lunar Operations Base (2008)
- Manned Mars Mission (2010)

The logic for the above lies in several areas. First, there are two space initiatives [Geosynchronous Multi-Function Communications Platform (1998) and Global Environment Monitoring System (2002)] which represent substantial benefits to the entire nation and will, therefore, retain their priority. Second, the national penchant for science and space exploration has not yet blossomed; priorities tend more toward national defense.

Low Model

The low TD mission model delays considerably the resolution of technology issues for the same space initiatives previously shown, with their initial operational dates slipped further.

- Large Astronomical Observatory (2004)
- Earth Orbiting Micro-Gravity Facility (2008)
- Lunar Operations Base (2010)
- Manned Mars Mission (2012)

The same logic as the medium model prevails, except the national zest for science and space exploration is non-existent; all priorities support national defense.

Estimating Size/Mass

Best engineering judgment of the probable size/mass of each mission was correlated with comparable experiment descriptions contained in the references shown in Table 3.7-3.

Table 3.7-3. Logic for Estimating Size/Mass

Item	Reference
Platforms (free-flyers and/or attached)	Spacelab
Free-flying satellites	P80-1, TMS
Lightweight structures Space telescopes	NASA's Space Systems Technology Model, OAST, September 1981. Advanced Space Systems Concepts and Their Orbital Support Needs, The Aerospace Corporation ATR 76(7365)-1, Revised. SPACE INDUSTRIALIZATION, Rockwell International, SD 78-AP-0053 (April 14, 1978).

Estimating Cost of Each Mission

The cost of each mission was estimated by using the relationship:

- $10,000/lb (average) for attached experiments
- $20,000/lb (average) for free-fliers

Each mission cost was spread over the anticipated acquisition years to establish a more realistic annual expenditure race.

Emphasis of the TD Missions

Construction of a credible TD mission model required a scenario geared to today's planning activities as well as tomorrow's goals and objectives. Our scenario for TD missions, therefore, looks at the anticipated technology needs of the 1980's, the 1990's, and the beginning of the next century in order to structure a model which will respond to (or satisfy) those needs.

With the initial operations of the Space Station planned for 1991, the majority of the test effort during 1981-1990 time period will be concentrated on maturing the Space Station design, with a few missions supporting science and applications as well as future initiatives. During the 1990's, with the Space Station operational, emphasis changes to predominant support to science and applications, with mild support to future initiatives. Starting at the turn of the century, emphasis changes again to predominant support to future initiatives (lunar base, manned Mars mission), with token support to advanced Space Station development and science and applications.

Table 3.7-4 illustrates the changing emphasis of the TD missions for the three time periods of interest to this study.

Table 3.7-4. Changing Emphasis of the TD Missions

Primary Support	1981-1990	1991-2000	2001-2010
Space Station	15	2	6
Science and Applications	3	11	6
Future initiatives	2	6	10

TECHNOLOGY DEVELOPMENT MISSION MODEL FOR SCENARIO NO. 6A (NO SPACE STATION)

Approach

Using Space Station as a national resource to aid in technology development has an inherent benefit of almost unrestricted time to thoroughly test and gather data on each experiment. Long-term effects can be readily explored in this environment for very little cost above that required to get the experiment into LEO. The nature of these TD missions, therefore, will tend toward relatively long on-orbit stay times in order to accomplish as much testing as possible and thoroughly resolve each technology issue.

In contrast to the above, TD missions without a Space Station are severely limited by on-orbit stay times. One impact of the limited time on orbit will be a dilution of test data (long-term effects will not be available from sortie missions). Another impact will be the reduced size of large space structures which can be deployed/assembed on any single mission. Multiple missions will, therefore, be required to assemble large space structures, with the added requirement for stabilization and control to permit subsequent docking/tethering. The net result is the extended time to resolve some technology issues.

The need to obtain long-term effects will drive certain experiments to the free flyers concept, which is inherently a more costly approach. Experiment costs will also be increased by the need for more automation in order to complete a planned orbital test within the time limit of the sortie mission.

Those TD missions which are normally planned as free flyers (caused by the need for a very low gravity field) will be unaffected by the lack of a Space Station, except the size of the structure will be limited. Servicing missions will now be controlled by ground operations, rather than Space Station operations.

Table 3.7-5 identifies each TD mission by name and year of launch.

Table 3.7-5. TD Mission Summary fôr Scenario 6A

Payload/Mission Name	Year										Total
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
Planetary space-craft ret								1	1		2
Advanced waste collector		1			1				1		3
Cryogenic transfer										1	1
Advanced emesis station	1										1
Multi-kW heat pipe performance		1									1
Remove/replace fuel cells				2							2
Spacecraft servicing							1				1
Spacecraft assembly	1					1					2
Low conc. ratio solar array		1									1
Full body shower demo			1	1							2
Portable solar flare warning					1						1
Fire suppression techniques					1						1
Mono/bi-propellant transfer							1				1
Spacecraft/OTV mating								1			1
Remove/replace LRU's										1	1
Medium Model Total	2	3	1	3	3	1	2	2	2	2	21

Model Construction Process (1991-2000)

Constrained by the NASA development budget, TD missions are expected to be concentrated primarily on those experiments which would benefit the (future) Space Station design and operations. This conclusion is based on the following information.

1. NASA's briefing on TD missions presented by Mr. S.V. Manson on September 14-15, 1982 at the Space Station Program Contractor Orientation Briefing. The briefing material contains descriptions of 21 experiments (38 percent of the total) which are directly related to Space Station development and, hence, affect its basic design and/or operations.

2. The key role that Shuttle sortie missions occupy in NASA's contractual effort for the study, Definition of Technology Development Missions, as evidenced by data presented at the interim reviews. Shuttle sortie missions are recommended for propellant transfer/storage development and OTV docking development. These preliminary recommendations reinforce the need for timely TD missions to support Space Station design and operational procedures.

3. NASA's Space Operations Center (SOC) Technology Program Plan, issued on October 23, 1981, by the Technology Program Definition Office.

The TD mission model for Mission Scenario 6A, therefore, includes the basic recommendations in the three information areas cited above. For these recommendations to be acted on, that portion of the TD model which supports Space Station development is subdivided into the following disciplines:

- Primary power (two missions)
- Environmental/life support (seven missions)
- Crew safety (six missions)
- Auxiliary propulsion (one mission)
- Propellant storage/transfer (six missions)
- Communication/tracking (one mission)
- Thermal control (two missions)
- Operations (six missions)
- Guidance and control (three missions)

Consistent with NASA's past activity in technology development, as well as 34 experiments described in the first information area mentioned above, the TD mission model for Mission Scenario 6A also contains significant support to science and applications as shown by the following subdivision.

- Primary power (one mission)
- Environmental/life support (four missions)
- Auxiliary propulsion (two missions)
- Thermal control (two missions)
- Communications/tracking (three missions)
- Guidance and control (four missions)
- Large space structures (two missions)
- Sensors (two missions)
- Space processing (four missions)

The logic of this model is that it provides support to Space Station development during the 10 years prior to its initial placement on orbit.

Table 3.7-6 summarizes the missions, net weight, and anticipated cost--all on a yearly basis.

Table 3.7-6. Mission Scenario 6A TD Mission Summary Data (Medium Model)

	Year									
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Launches per year	2	3	1	3	3	1	2	2	1	1
Weight (lb)	2,140	7,540	220	1,100	2,480	1,980	41,500	27,100	1,162	5,060
Cost, $\overline{M}$ (1984 dollars)	52.4	51.9	51.6	51.4	49.9	44.0	47.0	51.4	52.0	52.9

3.8 GEO SERVICING

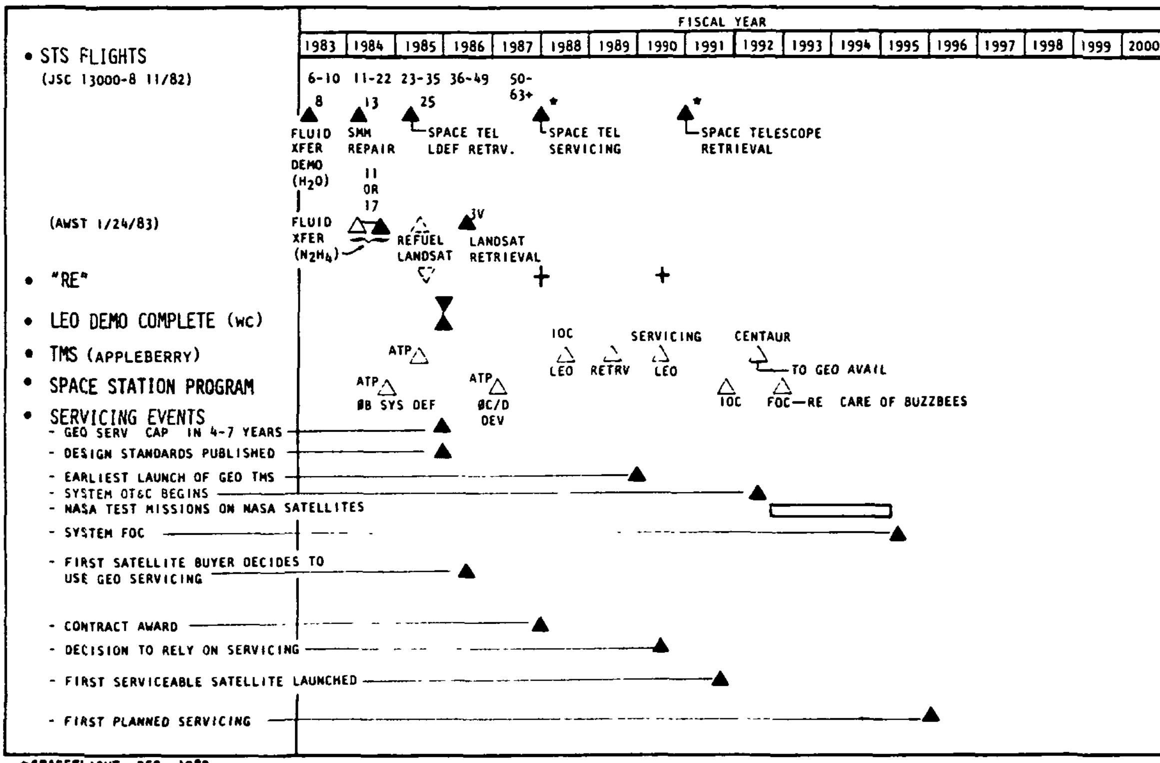
Space operations are maturing at such a rate that a dozen separate LEO servicing and/or retrieval operations or tests are scheduled by the end of the decade (Figure 3.8-1). A context for GEO servicing was established by building upon this operational schedule: (1) the Space Station and TMS development schedules were added, (2) a firm commitment to GEO servicing was assumed to be announced in 1985-1987, (3) and selected GEO satellite users and builders were assumed to embark on new satellite developments in about the same time period. These efforts would begin to culminate in the early 1990's. NASA communications applications efforts were assumed to produce an advanced communications platform to be launched in 1992 (described in Section 3.1) which both presses new technology and operates as a GEO servicing test bed. The concurrently developed serviceable satellites also begin to be launched in 1992, with a planned first servicing in 1996.

Based on user reaction obtained in this study, commercial communications satellite candidates for servicing were listed and a specific subset was chosen to be serviced (Figure 3.8-2). Similarly, three DOD satellites were chosen to be representative of this class of satellites (Table 3.8-1). A required servicing weight and frequency was specified for each of these chosen satellites (Tables 3.8-1 through 3.8-3). These basic elements were then used to create the manifest shown in Tables 3.8-4 through 3.8-7 for the medium traffic model.

With the medium mission model established from the above rationale, a high model was built to support the adjustments made in the high commercial communications model. There is no change in servicing requirements for GEO military satellites although additional military satellites at other locations are serviced (see Task 4.1 and 4.2). For both the Mission Scenario 6 low and 6A, no GEO servicing is assumed. There is insufficient traffic in the former and no Space Station in the latter; in neither is there sufficient economic justification until after the year 2000.

Table 3.8-8 summarizes the GEO servicing traffic for the medium and high models.

The GEO servicing elements build upon and within the then existing operational environment. The Space Station-based reusable PKM OTV will be used in concert with a permanently GEO-based (uprated) TMS, and expendable servicing module and apogee motor (AKM). The first TMS is launched to GEO in 1992 and the second in 1995. The weight statement for the GEO-TMS and servicing module is given in Table 3.8-9. Taken together, these elements use the reusable PKM OTV and AKM to place a maximum of 12,000 pounds net payload into GEO. Since the servicing module weighs 2,400 pounds this capability results in a delivery of 9,600 pounds net of servicing equipment and propellant/fluids on each servicing mission.



*SPACEFLIGHT, DEC. 1982

Figure 3.8-1. Operational Experience and Infrastructure Development

CRITERIA:

1ST SATELLITE IN THE SERIES LAUNCHED '92 OR LATER
ALL SATELLITES IN THE SERIES WILL BE SERVICED

CANDIDATES:

- AMERSAT - F/O
- BRASILSAT - F/O
- CBS-DBS - F/O
- ✓ DBSC - F/O
- ✓ FORDSAT - F/O
- G-STAR - F/O
- ✓ INTELSAT VII
- L-SAT - F/O
- NORDSAT - F/O
- ✓ RCA-DBS - F/O
- SATCAL - F/O
- ✓ SATCOM - F/O-2
- SPACENET - F/O
- STC DBS - F/O
- ✓ TDRS - F/O
- TELSTAR 3- F/O
- TELSTAR 4- F/O
- USSAT - F/O
- WESTAR - F/O
- WESTAR K- F/O
- FOREIGN LAUNCHED
  + PLATFORMS
  + UNSPECIFIED NEW SYSTEMS
    - 12 IN LOW MODEL
    - 23 IN MED. MODEL
    - 32 IN HIGH MODEL

✓= SELECTED

Figure 3.8-2. Candidate Commercial Communication Satellites for Servicing

Table 3.8-1. DOD GEO Serviced Satellites

NAME	ELEMENTS	WT	FREQUENCY
DOD 3	PROPELLANT	2,600 LB	1 EACH YEAR
	MAINTENANCE	400	
		3,000	
DOD 5G	PROPELLANT	2,500 LB	1 EACH 2 YEARS
	MAINTENANCE	500	
		3,000	
DOD 7G	PROPELLANT	2,600	1 EACH YEAR
	MAINTENANCE	600	
		3,200	

Table 3.8-2. Recommended Servicing Model

	(MISSION SCENARIO #6, MEDIUM)								
	'92	'93	'94	'95	'96	'97	'98	'99	'00
INTELSAT VII					F1		F3	F5	F1 F7
TDRS F/O					1	2	3	4	1
DBSC F/O						1		2	3
RCA DBS - F/O						1		2	3
FORDSAT - F/O								1	1
SATCOM F/O - 2								1	2
PLATFORMS P1							1		
PLATFORMS P2								1	
PLATFORMS P3									1
TOTAL					2	3	3	7	8

Table 3.8-3. Weight to GEO

	PROPELLANTS (5% OF S/C WT.)		HARDWARE (10-15% OF S/C WT.)		
• INTELSAT VII (1996)	375 LB				
• INTELSAT VII SUBSEQUENT	375 LB		950 LB		
• TDRS F/O (1996)	375 LB				
• TDRS F/O SUBSEQUENT	375 LB		950 LB		
• DBSC F/O	200 LB		500 LB		
• RCS DBS F/O	150 LB		360 LB		
• FORDSAT	160 LB		390 LB		
• SATCOM F/O-2	110 LB		270 LB		
• PLATFORMS	600 LB		1800 LB		
	'96	'97	'98	'99	'00
TOTAL MASS TO ORBIT (FOR COMM.) LB	750	2535	5050	7190	8515

Table 3.8-4. GEO-Servicing Manifests for 1996-97

SET NAME	SATELLITE SERVICE WEIGHT	SPECIFIC TT&C	SPECIFIC ΔV	OVERHEAD TT&C	OVERHEAD SM R&D + PARK	
96-1						
DOD 3_1	3,000	7 DAYS	157 LB	15 DAYS	1.75	
DOD $5G_1$	3,000					
INTELSAT VII	375					
COMM. APPL.	1,000	7 DAYS	157 LB	15 DAYS	1.75	
NET	7375, 4 SATS	28 DAYS	628 LB	60 DAYS	7 DAYS	95 DAYS GND CONT.
TMS PROP	628 + SERV. MOD. 2400 = 3028					
GROSS	10,403 LB →	10,700				
96-2						
DOD 3_2	3,000	7 DAYS	157 LB	15 DAYS	1.75	
DOD $5G_2$	3,000					
TDRS $F/0_A$	375					
CONTINGENCY	375	7 DAYS	157 LB	15 DAYS	1.75	
NET	6750, 4 SATS	28 DAYS	628 LB	60 DAYS	7 DAYS	95 DAYS GND CONT.
TMS PROP	628 + SERV. MOD. 2400 = 3028					
GROSS	9,780 LB					
97-1						
DOD 3_3	3,000	7 DAYS	157 LB	24 DAYS	1.4	
DOD 3_4	3,000					
TDRS $F/0_B$	1,325					
RCA SATCOM K $F/0_A$	350	7 DAYS	157 LB	24 DAYS	1.4	
NET	7675, 4 SATS	28 DAYS	628 LB	120 DAYS	7 DAYS	162 DAYS GND CONT.
TMS PROP	628 + SERV. MOD. 2400 = 3028					
GROSS	10,700 LB					

NOTE: GEO SERVICING OPERATIONAL PHASE. MISSIONS SIZED FOR 9.6 KLB NET TO GEO, AND ΔV's PROVIDE AN AVERAGE OF 3°/DAY DRIFT BETWEEN SATELLITES.

Table 3.8-5. GEO-Servicing Manifest for 1998

SET NAME	SATELLITE SERVICE WEIGHT	SPECIFIC		OVERHEAD		
		TT&C	ΔV	TT&C	SM R&D + PARK	
98-1						
DOD 3_5	3,000	7 DAYS	158 LB	13 DAYS	2.33	
DOD 3_6	3,000	7 DAYS	158 LB	13 DAYS	2.33	
DOD $5G_3$	3,000	7 DAYS	158 LB	13 DAYS	2.33	
NET	9000, 3 SATS	21 DAYS	474 LB	40 DAYS	7 DAYS	68 DAYS GND CONT
TMS PROP	474 + SERV.MOD. 2400 = 2874					
GROSS	11,875 LB →	12,000				
98-2						
COMM. APPL.	1,000					
DOD $5G_4$	3,000	7 DAYS	158 LB	13 DAYS	2.33	
DOD $7G_1$	3,200	7 DAYS	158 LB	13 DAYS	2.33	
INTELSAT VII_C	1,325	7 DAYS	158 LB	13 DAYS	2.33	
NET	8525, 4 SATS	21 DAYS	632 LB	40 DAYS	7 DAYS	68 DAYS GND CONT.
TMS PROP	632 + 2400 = 3032					
GROSS	11,557 LB →	12,000				
98-3						
TDRS F/O_G	1,325	7 DAYS	157 LB	10 DAYS	1.75	
DOD $7G_2$	3,200					
RCA SATCOM K_B	350					
$TDRS_C$	1,325					
MUS-I	7,000	7 DAYS	157 LB	10 DAYS	1.75	
NET	8200, 5 SATS	35 DAYS	785 LB	50 DAYS	7 DAYS	75 DAYS GND CONT.
TMS PROP	785 + 2400 - 3185					
GROSS	11,385 LB	12,000				

Table 3.8-6. GEO-Servicing Manifest for 1999

SET NAME	SATELLITE SERVICE WEIGHT	SPECIFIC		OVERHEAD		
		TT&C	ΔV	TT&C	SM R&D + PARK	
99-1						
DOD $7G_3$	3,200	7 DAYS	158 LB	20 DAYS	2.33	
DOD $7G_4$	3,200	7 DAYS	158 LB	20 DAYS	2.33	
INTELSAT VII_E	1,325	7 DAYS	158 LB	20 DAYS	2.33	
NET	7725, 3 SATS	21 DAYS	474 LB	60 DAYS	7 DAYS	88 DAYS GND CONT.
TMS PROP	474 + 2400 = 2874					
GROSS	-10,600	10,700				
99-2						
DBSC $F/0_A$	700	7 DAYS	137 LB	9 DAYS	1	
RCA SATCOM K $F/0_C$	350					
FORDSAT $F/0_A$	550					
RCA SATCOM $F/0\text{-}2_A$	3,000					
CONTINGENCY	1,500					
TDRS $F/0_D$	1,325	7 DAYS	137 LB	9 DAYS	1	
NET	7805, 7 SATS	49 DAYS	959 LB	60 DAYS	7 DAYS	116 DAYS GND CONT.
TMS PROP	959 + 2400 = 3359					
GROSS	11,164	12,000				

Table 3.8-7. GEO-Servicing Manifest for 2000

SET NAME	SATELLITE SERVICE WEIGHT	SPECIFIC		OVERHEAD		
		TT&C	ΔV	TT&C	SM R&D + PARK	
00-1						
INTELSAT VII_A	1,325	7 DAYS	132 LB	12 DAYS	1.4	
INTELSAT VII_G	1,325					
TDRS $F/0_A$	1,325					
DBSC $F/0_B$	700					
RCA SATCOM K $F/0_D$	350					
NET	5025, 5 SATS	35 DAYS	660 LB	60 DAYS	7 DAYS	102 DAYS TT&C
PROP + MOD	3,185					
GROSS	8,210 9,780					
00-2						
FORDSAT $F/0_B$	550	7 DAYS	157 LB	15 DAYS	1.75	
COMM. APPL.	1,000					
RCA SATCOM $F/0\text{-}2_B$	380					
MUS-II	3,000	7 DAYS	157 LB	15 DAYS	1.75	
NET	4930, 4 SATS	28 DAYS	628 LB	60 DAYS	7 DAYS	95 DAYS TT&C
PROP + MOD	3,028 LB					
GROSS	7,958 LB → 9780 LB					

Table 3.8-8. GEO Servicing Mission Model Summary for Scenario 6

	YEAR										TOTAL
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	
Missions Medium Model					1	2	1	3	2	2	11
Missions High Model					1	2	2	4	3	3	15

Table 3.8-9. Servicing Mission Weight

SERVICING MODULE

0.8 "MASS FRACTION" x 12,000 LB GROSS = 9600 LB NET SERVICING TO GEO

= 2400 LB MODULE

TMS-GEO (BIPROP.)	WEIGHT (LB)
BASIC	2,545
RENDEZVOUS/DOCK	330
SERVICER	540
GEO POWER	270
GEO TT&C	50
MSC	50
$\omega_{B.O.}$	3,785
ω_P	6,700
TOTAL	11,485

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4.0 TIME-PHASED SPACE STATION REQUIREMENTS

The time-phased user mission support resource requirements, Space Station facility resource requirements, and the total integrated system resource requirements are presented in this section. The logic of this presentation is to (1) describe the approach utilized to time-phase the mission requirements, (2) summarize the results of the supporting studies that developed the station mission accommodation scenarios and supporting systems operational concepts, (3) define the user mission payload support requirements, (4) summarize the results of the supporting studies that developed the station facility requirements, and (5) define the integrated time-phased station system requirements.

4.1 APPROACH TO TIME PHASING OF MISSION REQUIREMENTS

The approach used to develop mission requirements and to time phase those requirements is illustrated in Figure 4.1-1. This procedure is initiated by organizing an input data set extracted from the mission model data base, the ESTS program concept definition and evaluation, the Mission Scenario 6 STS manifesting data, and the Mission Scenario 6 mission model.

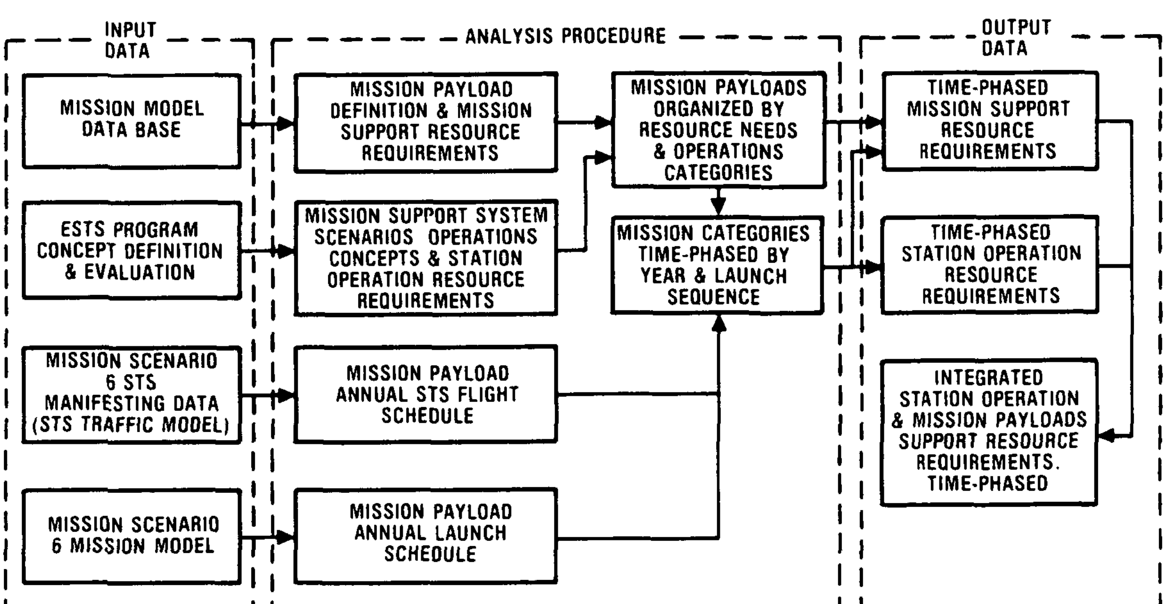


Figure 4.1-1. Approach to Time-Phasing of Mission Requirements

The mission model data base provides mission descriptions, objectives, and basic hardware scenarios. These data are used to establish mission resource requirements and the schedule of Space Station services required for each mission resource requirement and the schedule of Space Station services required for each mission payload.

The ESTS program concept definition and evaluation provides mission support system scenarios, operations concepts, and station operation facility resource requirements.

The Mission Scenario 6 model provides the annual launch schedule for each payload and the total mission payload content in each model year.

The Mission Scenario 6 manifesting data provides the detailed STS launch scheduling and orbiter payload content for each model year. The mission support system scenarios include not only the Space Station but also the mission payload interfaces and interactions with the OTV, TMS, space platforms, and other space support systems. The input data analysis is conducted for each of the low, medium, and high model levels.

This input data set is then used in an analysis procedure to organize the mission payloads that have been shown to derive benefits from being accomplished at or processed through the Space Station by resource needs and operations categories. These resource needs and operations categories are those that are considered realistic and validated through the user contact interaction. The categories enable the grouping of all missions that require essentially the same station resources or system services. As an exmaple, a list of all mission payloads that require placement into a high-energy orbit by the OTV is generated and organized by the particular destination orbits. These data are then integrated with the mission payload annual launch schedule and annual STS flight schedule to obtain a time phasing of the mission categories and the mission payloads within those categories by year and launch sequence.

The outputs of this analysis procedure are time-phased user mission support resource requirements and time-phased station facility operation resource requirements. Requirements data summarized and presented in this report are for the resource and service areas of crew hours, power, data rates, attitude pointing, disturbances, station storage or working volume, and propellant use and storage. These requirements are developed in the two separate listings of user and facility so that it can be understood what the set of user needs for station resources and services are, as opposed to how large a station facility and what other ESTS elements are required in order to provide the needed resources and services. Therefore, integration of these two listings yields a set of the total station facility and user mission payloads support resource and service requirements that is time phased by study year.

4.2 SYSTEM SIZING SUMMARY

The principal issues affecting the development of user mission support and facility requirements are the flow of mission payloads being operated at, processed through, or stored at the Space Station, and operational scenarios of the space support systems necessary for the execution of user mission objectives. The key drivers resulting from these issues in the areas of mission model mass flow, station-based OTV operations, station-based TMS operations, accommodation of station-attached missions, the assignment of ASE to the mission payloads for Shuttle manifesting, and the resulting manifested Shuttle traffic models are summarized in this section.

MISSION MASS FLOW

Show in Figure 4.2-1 are the mission payload mass flows to earth orbit as defined by the Mission Scenario 6 mission model. These mass flows represent only the mass associated with the mission payload end items delivered to the destination orbits, and do not include other masses required to accomplish the missions. These support system items typically include orbiter cargo bay ASE, upper stages and propellants, and servicing equipment. The mass flow data are shown time phased by model year and orbit inclination for the medium model along with a summation for the total mass delivered to each inclination through the year 2000 and for all three model levels. Also indicated for the medium model is a breakdown of the total mission payload masses by user mission area. Of these, it is the low inclination (28.5 degrees) missions and the high-energy orbit missions from the medium inclination set (nominally 57 degrees) that are processed through the recommended program Space Station.

STATION-BASED OTV OPERATIONS

To maximize the Space Station program benefits, the OTV system must employ a highly efficient least-cost approach. The supporting studies traded many combinations of cryogenic, storable, and solid-fueled OTV's including single-stage, two-stage, expendable, reusable, ground-based, and space-based configurations. Also, where appropriate, these combinations were traded for general multimission designs versus custom designs tailored for specific mission payloads or integral approaches. The results of these trades, as well as the selected baseline approach, are illustrated in Figure 4.2-2.

The selected program baseline is a space-based, cryogenic-fueled, PKM OTV-based and serviced at the station. To complete the system, the user mission spacecraft employs an integral storable propellant AKM. As the graph shows, this system has considerable cost advantages over the alternative approaches. The station resource and mission payload requirements that are presented in this report were developed utilizing this baseline OTV approach, which is sized to place a maximum of 24,600 pounds into geosynchronous transfer orbit. In

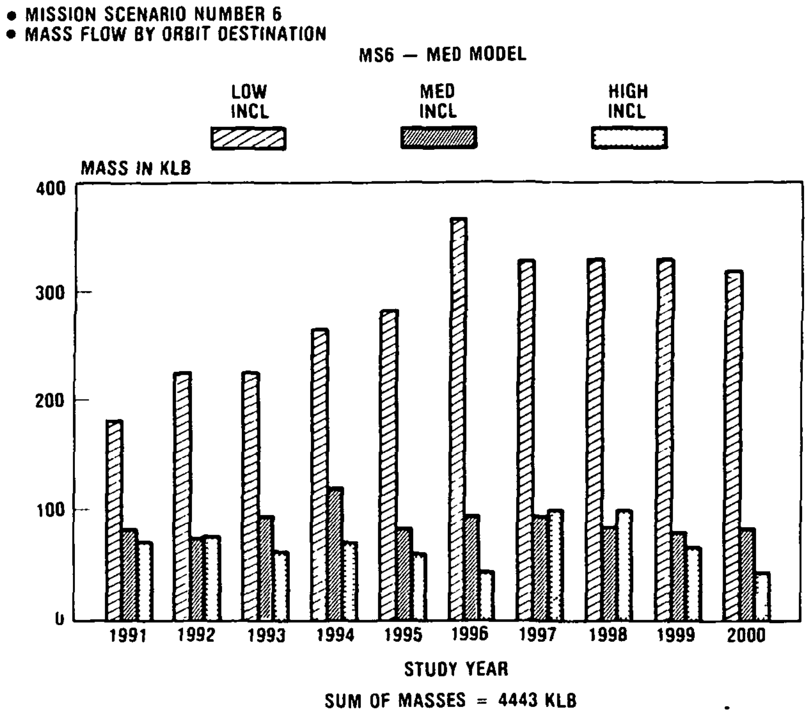
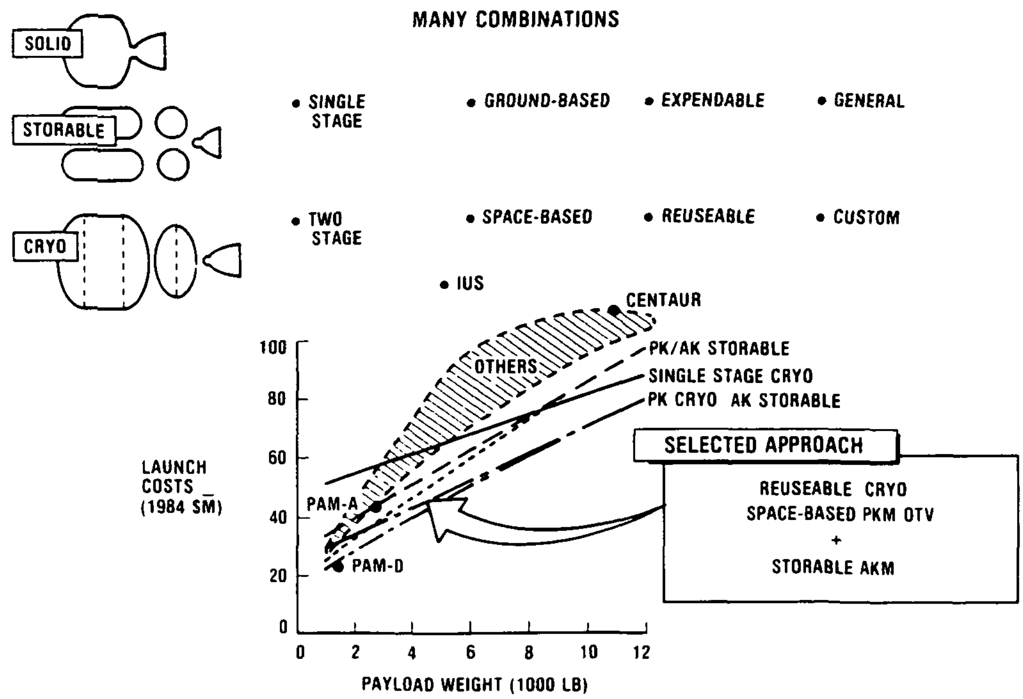


Figure 4.2-1. User Mission Payload Mass Flow Summary

addition, the capability to manifest multiple payloads on the OTV, as well as the capability to off-load the OTV for lighter mission payloads, were employed in the developement of the requirements. This PKM OTV concept greatly reduces propellant requirements over earlier concepts utilizing a large single-stage OTV FOR GEO deliveries.

Another important mission area that impacts the requirements definition, as well as the OTV operations, is the servicing of spacecraft located in geo-synchronous orbit. The approach to GEO servicing utilized in Mission Scenario 6 is depicted in Figure 4.2-3. Key features of this approach are the permanent basing in GEO of two uprated TMS vehicles, the use of a reusable space-based PKM, and an expendable servicing module integrated with a storable propellant AKM. Each GEO based TMS services half the orbital arc. The TMS and expendable service module are illustrated in Figure 4.2-4.

The schedule of events that leads to operational GEO servicing begins with the launch of a communications applications technology platform in 1992. This is followed by the first GEO servicing demonstration mission in 1993, and the initiation of planned operational GEO servicing missions in 1996. This scenario assumes concurrency on the part of GEO spacecraft owners and developers because of the lead time associated with spacecraft design changeovers.



• MODEL SUMMATION BY ORBIT DESTINATION & MODEL LEVEL (1991-2000)

ORBIT DESTINATION	MISSION MODEL LEVEL					
	MEDIUM		LOW		HIGH	
	TOTAL MISSION PAYLOAD MASS (KLB)	DIST (%)	TOTAL MISSION PAYLOAD MASS (KLB)	DIST (%)	TOTAL MISSION PAYLOAD MASS (KLB)	DIST (%)
LOW INCLINATION	2830	64	1662	53	5128	46
MEDIUM INCLINATION	902	20	309	28	1114	29
HIGH INCLINATION	711	16	577	19	1156	25
• TOTAL	4443	100 0	2548	100 0	7398	100 0

• MODEL SUMMATION BY USER MISSION AREA (1991-2000)

USER MISSION AREA	MISSION MODEL LEVEL					
	MEDIUM		LOW		HIGH	
	TOTAL MISSION PAYLOAD MASS (KLB)	DIST (%)	TOTAL MISSION PAYLOAD MASS (KLB)	DIST (%)	TOTAL MISSION PAYLOAD MASS (KLBS)	DIST (%)
COM COMMUNICATIONS	522	11 8	349	13 7	802	10 8
COM PROCESSING	639	14 4	440	17 3	864	11 7
COM RESOURCE OBS	39	0 9	28	1 1	47	0 7
DOD	2431	54 7	1180	46 3	4803	64 9
GEO SERVICING	118	2 7	—	—	165	2 2
GOVT ENVIRONMENTAL	41	0 9	41	1 6	41	0 6
NASA SCI & APPL	567	12 7	467	18 3	580	7 8
NASA TECHNOLOGY	86	1 9	43	1 7	96	1 3
• TOTAL	4443	100 0	2548	100 0	7398	100 0

Figure 4.2-2. OTV Trade Summary

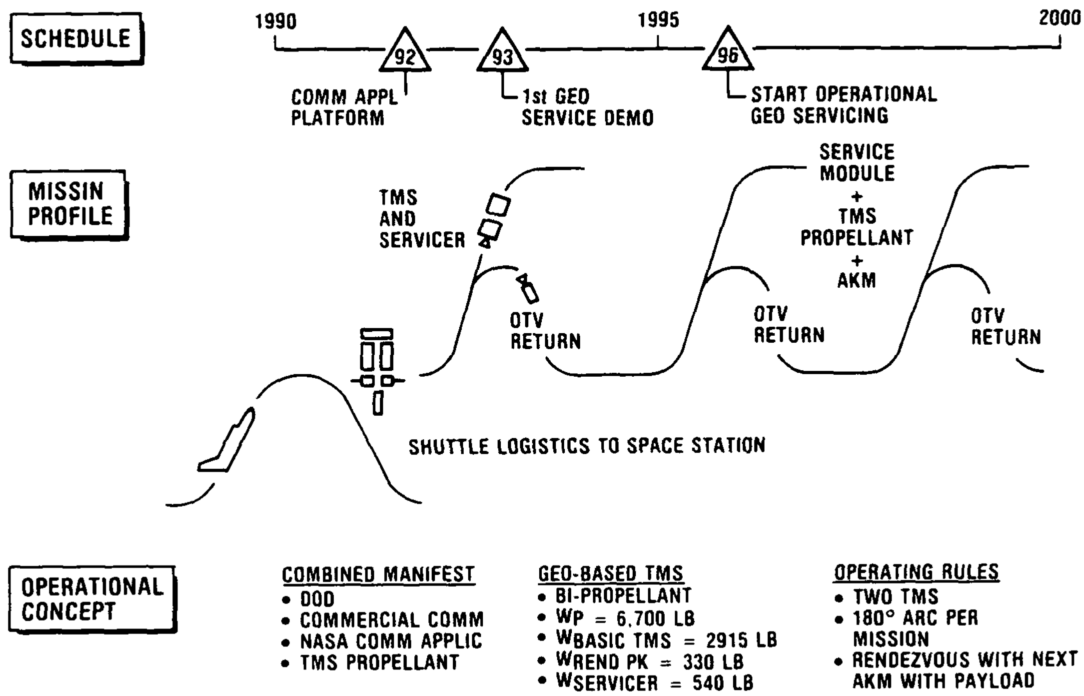


Figure 4.2-3. GEO Servicing Concept

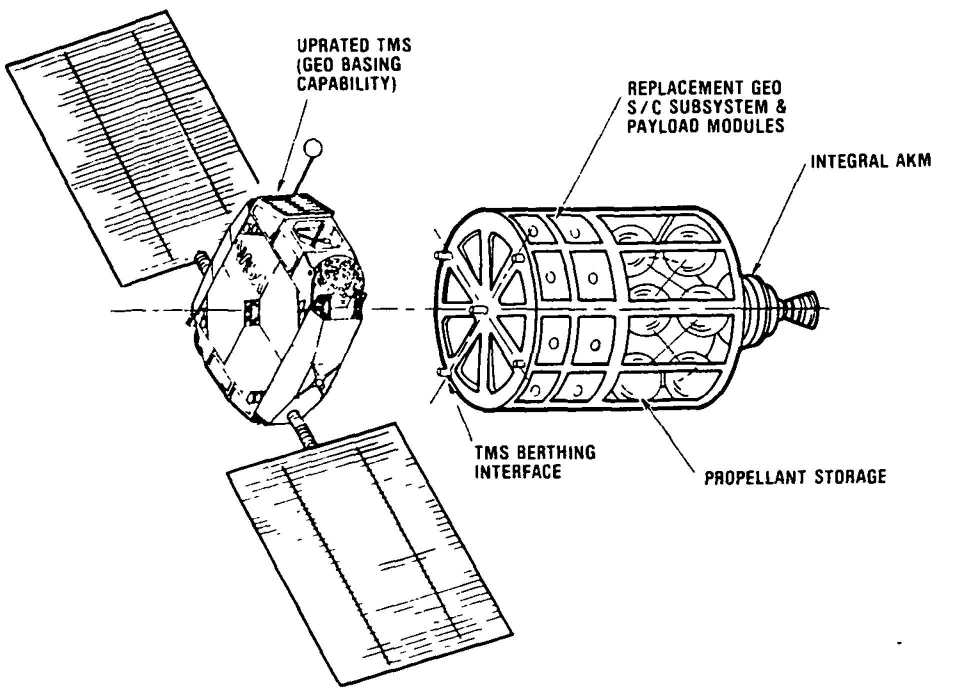


Figure 4.2-4. GEO-Based TMS and Expendable Service Module

An announced commitment to GEO servicing in the 1985 to 1988 time frame would allow owners and developers the option of incorporating serviceability into their next satellite design. The first serviceable satellite would be launched in the 1991 to 1993 time frame with the first planned servicing occurring in 1996. This scenario would allow for unscheduled and unplanned servicing to occur on these satellites as early as 1993 if required.

The GEO servicing mission profile begins with delivery of the mission payload elements to the Space Station in the expendable servicing module/AKM by the Shuttle orbiter. The servicing module has a capability to carry 9,600 pounds of servicing elements including propellants; its dry weight is 2,400 pounds. After integration with the OTV, the OTV places the servicing module into geosynchronous transfer orbit and returns to the station. The AKM provides the GEO insertion burn. The GEO-based TMS makes rendezvous with the passive servicing module and then proceeds around the GEO arc to service the scheduled spacecraft. The TMS then places the residual servicing hardware and spent spacecraft replacement modules into a higher debris parking orbit and returns to its GEO basing position.

The operational concept utilizes the full capability of the Space Station through combined manifesting where DOD, NASA, and commercial payloads, as well as the TMS propellant, are integrated through the basing of the TMS in GEO. The operational ground rules then require two TMS vehicles based in GEO, where each vehicle services up to 180 degrees of the orbit arc on each mission and returns to a parking position ready for rendezvous with the next AKM/servicing module assembly.

The cryogenic propellant delivery concept baselined for Space Station operations (OTV and station RCS) utilizes a propellant top-off approach combined with propellant scavenging of flight performance reserves from the Shuttle external tank. This concept is illustrated in Figure 4.2-5. The Space Station propellant delivery requirements are based on the Orbiter Vehicle 103 payload delivery capability to the nominal Space Station orbit of 200 nautical miles. This capability is the performance baseline utilizing 109-percent main engines and filament-wound solid rocket boosters. When allowances are accumulated for rendezvous, 20,000 pounds of nominal down cargo, a four-person crew, and a nominal three-day flight, the resulting delivery capability to the station is 61,000 pounds. The concept utilizes a specially designed top-off tank set located in the orbiter cargo bay. This tank set is 9 feet in length, has a dry weight of 2,550 pounds, and has a 24,000-pound capacity of LO_2 and LH_2 loaded at a 6:1 mixture ratio. Depending on the manifested cargo load in a given Shuttle flight, the propellant tank set is loaded with top-off propellant to bring the cargo load up to the 61,000-lb capability. When the 8,000 pounds of propellant scavenged from the external tank after main engine cutoff are added, the total delivery capability is increased to 69,000 pounds. This concept, therefore, yields effective orbiter cargo load factors greater than unity for the flights manifested to the Space Station. The mission and station cryogenic propellant delivery, storage, and usage requirements presented in this report were generated utilizing this propellant delivery concept.

The mission profile and Scenario 6 flight schedule for the selected OTV approach are presented in Figure 4.2-6. The PKM OTV is designed with a specific impulse of 470 seconds and a mass fraction of 0.873. In order to accomplish the design mission, this results in a propellant loading requirement of 24,500 pounds of LO_2 and LH_2 at a 6:1 mixture ratio and a stage burnout weight of 3,544 pounds. After checkout and integration with the user mission payloads at the Space Station, the OTV provides the GEO transfer function and returns to the station. The AKM then circularizes the mission payload into GEO. As delineated previously, the AKM is an integral stage, custom-designed for each class of spacecraft. It utilizes storable propellant and is sized for a specific impulse of 310 seconds. In addition to the GEO insertion function, it provides the spacecraft GEO stationkeeping functions.

The OTV flight schedule by model year is shown through the year 2000 for the low, medium, and high mission model levels. The initial operational capability (IOC) of the OTV for all three model levels is 1994. In order to support this operational capability, OTV demonstration and test missions are conducted in 1993. As shown, the peak medium model flight rates that must be supported by the Space Station are 21 and occur in the years 1995 and 1997.

STATION-BASED TMS OPERATIONS

The baseline program concept incorporates a TMS based at the Space Station in order to meet satellite servicing and delta velocity requirements in LEO relatively close to the station. The operations of the station-based TMS are summarized in Figure 4.2-7. These operations are principally the placement of observatory and national security spacecraft free flyers into higher orbits and the servicing of free flying spacecraft co-orbiting with the station. A delta altitude of approximately 160 nautical miles above the station orbit can be achieved for the typical observatory and national security free flyer in the Scenario 6 mission model.

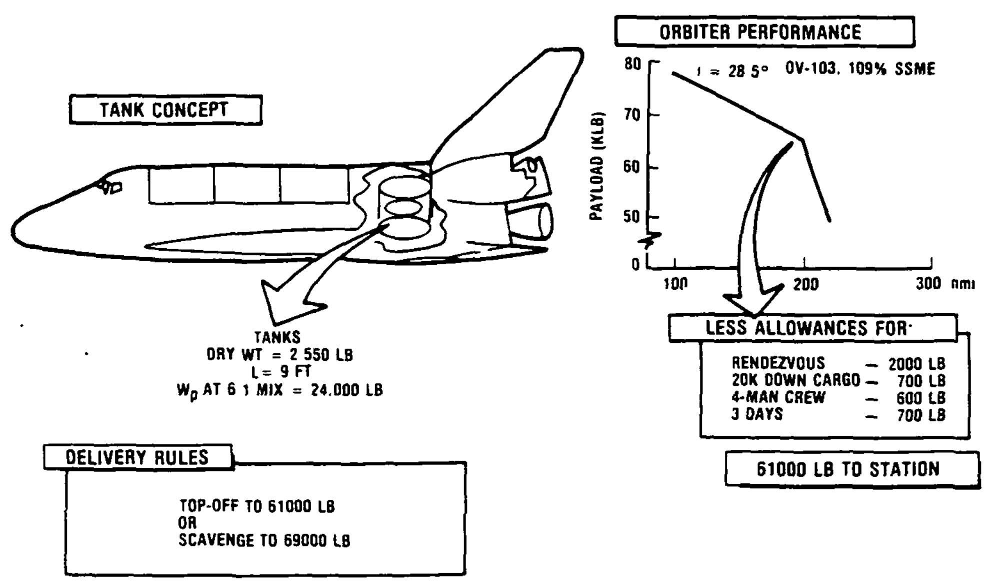


Figure 4.2-5. Propellant Delivery Summary

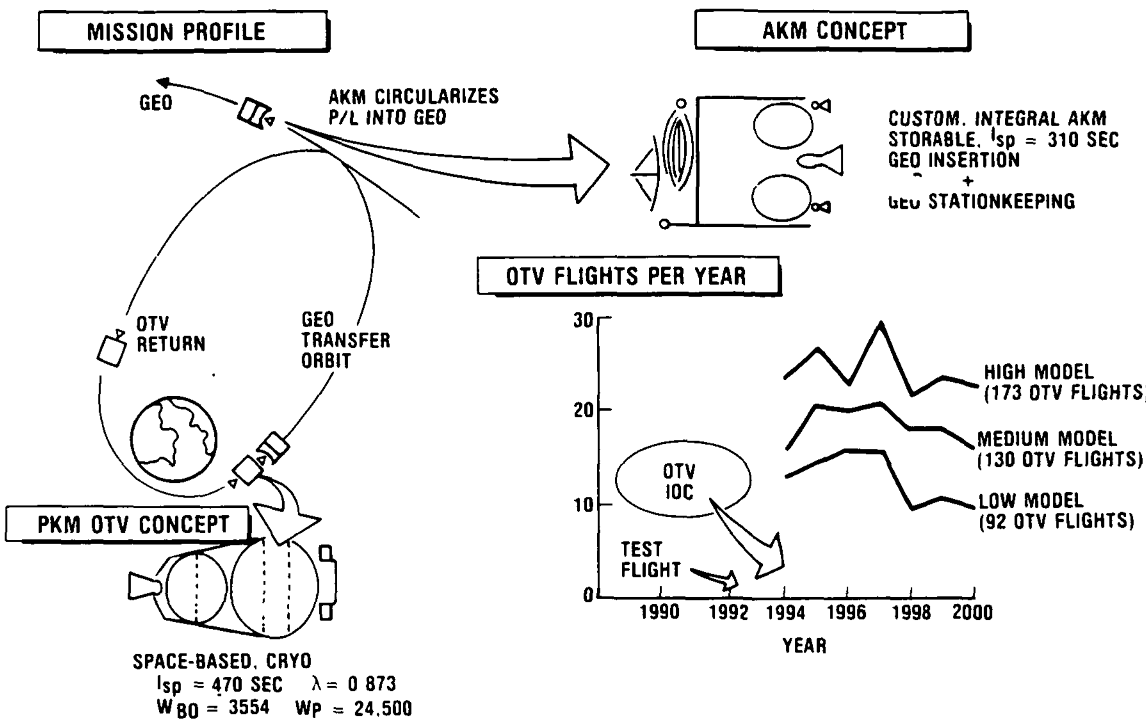


Figure 4.2-6. OTV Traffic Summary

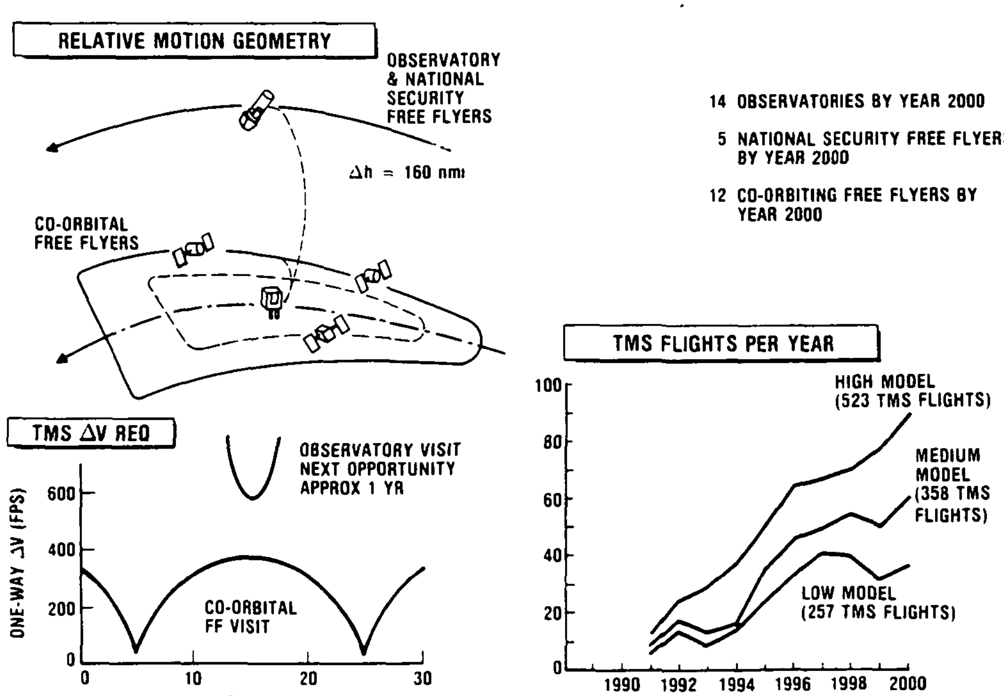


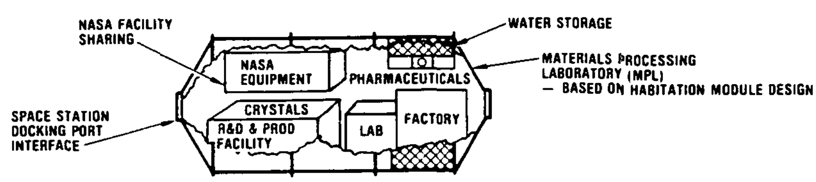
Figure 4.2-7. Station-Based TMS Operations Summary

The co-orbital free flyers are maintained in a known formation relative to the Space Station through a reboost strategy that places them above the station after their orbits have decayed to a predetermined position below the station. The propellant resupply required for this reboost strategy is provided by a servicing mission utilizing the station-based TMS. The TMS delta velocity requirements for these operations are shown as a function of visit opportunity. For the observatories and national security free flyers this requirement is 600 feet per second with a visit opportunity cycle of approximately one year. The co-orbital free flyer requirement varies from 50 to 400 feet per second with the minimum occurring on periodic cycles whose intervals depend on the drag characteristics of the free flyers.

The number of observatories, national security spacecraft, and co-orbiting free flyers contained in the Scenario 6 mission model that interface with the TMS are also summarized for the medium mission model, and the TMS flight rate is summarized by model year. These data show peak activity of 61 TMS flights occurring in the year 2000, and a total of 356 TMS flights for the medium model through the year 2000.

STATION ATTACHED MISSIONS

The Space-Station-attached commercial space processing functions are performed by utilizing a materials processing laboratory (MPL) module delivered in late 1991 and secured to a Space Station docking port (Figure 4.2-8). The



HOW ACCOMMODATED
- NASA APPLICATIONS PROCESSING SHARES MPL FACILITY
- MPL DELIVERY AND ATTACHMENT TO SPACE STATION IN 1991
- MPL DEDICATED TO PHARMACEUTICAL & CRYSTAL R&D AND PRODUCTION THROUGH 2000

ACTIVITIES/FUNCTIONS
- GALLIUM ARSENIDE CRYSTAL GROWTH/PRODUCT EXCHANGE & MAINTENANCE
- 2 1 POUNDS OF FINISHED CRYSTALS PRODUCED WITH 44 INGOTS ACTIVE
- *CONCENTRATION OF PHARMACEUTICALS/FACILITY STERILIZATION & CLEANUP*
- 5K POUNDS OF WATER PURIFICATION/HANDLING PER FF RESUPPLY

R & D PRODUCTION OUTPUTS	UNITS	PHARMACEUTICALS	CRYSTALS
• R&D — EXPERIMENTS	PER YEAR	28	288 0 ①
— EQUIPMENT UPDATES	LB/YEAR	750	840 0
• PRODUCTION — PRODUCTS	PER YEAR	4	1 (1990) TO 6 (2000) ②
— EQUIPMENT UPDATES	LB/YEAR	705	630 0

① REPRESENTS 6 CARTRIDGES & 48 TWO-HOUR FURNACE OPERATIONS/YEAR
② PREDICATED ON USER DEMAND INCREASE FROM 75 LB TO 7100 LB

STATION SERVICES REQUIRED
- CREW 2967 MAN-HOURS/YEAR (MINIMUM) TO 8843 MAN-HOURS/YEAR (MAXIMUM)
- POWER kW (56 4 kWh/DAY) FOR CRYSTAL FURNACE. 4 kW (CONTINUOUS) FOR PHARMACEUTICALS
  - NASA SHARING AVERAGES ABOUT 5 kW
- VOLUME. 40 FT LONG X 14 FT DIA IN DEDICATED MPL
- DATA HANDLING TBD
- SPECIAL CONDITIONS $\approx 10^{-5}$ g FOR 6 HOURS/DAY
- WATER PURIFICATION REQUIRES 0 4 kW IN 1991 & INCREASES TO 4 5 kW IN 2000

Figure 4.2-8. Station-Attached Commercial Space Processing

The MPL is a basic habitation module shell, 38.7 feet long by 13.7 feet diameter (internal), modified to contain the crystal and pharmaceutical R&D and production facilities as well as a shared volume (approximately 15 percent) for NASA equipment. Tankage for 7,700 pounds of water storage must also be provided to support the production of pharmaceutical productions. The 28 pharmaceutical experiments per year reflect a major investment based on the high cost of the raw products and a high risk for the invested dollar. The crystal laboratory produces semiconductor products (gallium arsenide, [GaAs]) to support an increasing demand in the electronics industry and for military weapons systems applications.

The station attached science mission area depicted on Figure 4.2-9 can be described in terms of life science experimentation, NASA applications processing, and the planetary (astrodynamics study area). Life sciences investigations start out in the early 1990's in the Space Station habitation module. As experiments progress, the experiments expand to the tunnel module and ultimately to an attached animal research facility by the late 1990's. The tunnel module will ultimately become a medical research facility much like a small hospital. The planetary and astrophysics instruments will be attached to and operated from the Space Station via a dedicated payload service assembly, and later released to operate in a free-flying mode.

NASA Technology Development, as attached to the Space Station facility, is illustrated in Figure 4.2-10. Internal functions involve two missions which accounts for approximately eight percent of the overall effort. The station-attached operations represent the major effort (57 percent) and deal with tests to evaluate the long-term effects of the space environment and to verify on-orbit performance. Crew EVA is required and must be planned for. Microgravity levels are important and isolation from the perturbations of the Space Station is essential. Ideally, a method of tethering would resolve the problem and is currently under study for this application. Close (8 percent) and free-flying satellites (27 percent) complete the scope of technology development tests.

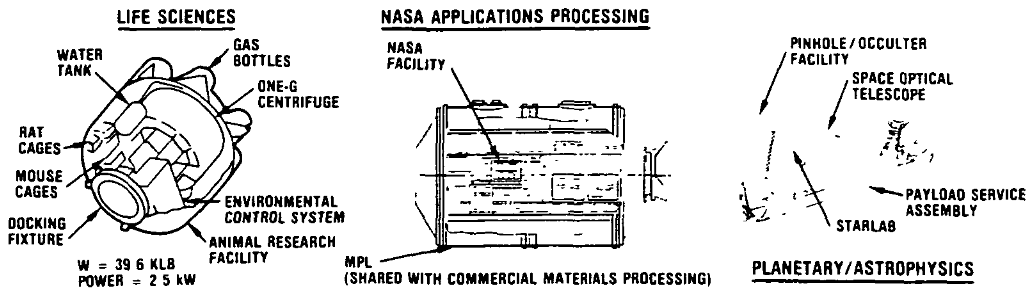
ASE ACCOUNTING APPROACH

To complete the orbiter manifesting, which determines the flow of user mission payloads to the Space Station, the ASE items must be accounted for. The ASE weight represents a significant portion of the total cargo weight delivered on each orbiter flight. As such, the ASE accounting must be realistic in order to obtain a valid orbiter flight rate. The approach utilized is to incorporate known ASE weights wherever possible and use existing ASE weight trends for estimating by payload class or category. The principal ground rules established for this purpose are summarized as follows.

- All spacecraft with PAM D or PAM D2 stages use the PAM D cradle as ASE.

- All spacecraft with PAM A upper stages use the PAM A cradle as ASE.

- All spacecraft using the IUS upper stage use the IUS cradle as ASE.

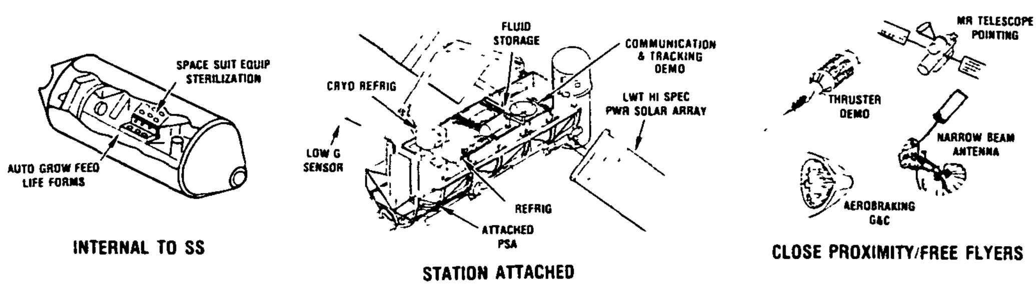


HOW ACCOMMODATED
- LIFE SCIENCES HOUSED IN SS HABITATION MODULE, TUNNEL MODULE, ATTACHED FACILITY
- APPLICATIONS PROCESSING IN MPL (5 KLB FURNACE AND 1 1 KLB/YEAR MATERIALS)
- PLANETARY/ASTROPHYSICS ON PAYLOAD SERVICE ASSEMBLY, CONTROL CONSOLE WITHIN SS

ACTIVITIES/FUNCTIONS
- MONITORING STATUS
- INTERACTIVE PARTICIPATION IN LIFE SCIENCES
- INSTALLATION AND MAINTENANCE OF EQUIPMENT
- ASSEMBLY, CHECKOUT, ENHANCEMENT OF SATELLITES

STATION SERVICES REQUIRED
- CREW 227 MAN-HOURS/YEAR (MINIMUM) TO 2185 MAN-HOURS/YEAR (MAXIMUM)
- POWER 9 kW (1991) TO 15 kW (1998)
- VOLUME LIFE SCIENCES, 2000 FT^3, APPLICATIONS PROCESSING, 300 FT^3, PLANETARY/ASTROPHYSICS, 100% OF PSA
- DATA HANDLING TBD
- SPECIAL CONDITIONS
  - LOW GRAVITY
  - BEYOND ATMOSPHERE
  - LONG DURATION
  - EARTH SURVEILLANCE

Figure 4.2-9. Station-Attached Science



HOW ACCOMMODATED
- INTERNAL TO SS — LIFE FORMS & EQUIPMENT STERILIZATION (2 MISSIONS)
- STATION ATTACHED VIA PAYLOAD SERVICE BAY/FIXTURE ASSEMBLY (15 MISSIONS)
- CLOSE PROXIMITY/FREE FLYERS IN LEO (9 MISSIONS)

ACTIVITIES/FUNCTIONS
- FLUID TRANSFER ASSEMBLY, CHECKOUT SERVICING SAFING, DEPLOYMENT, AND RETRIEVAL OPERATIONS
- COMMUNICATIONS TRACKING REMOTE HANDLING/CONTROLLING AND MONITORING FUNCTIONS
- DATA HANDLING ANALYSIS MONITORING AND TRANSFERRING TASKS
- EVA ATTACHMENT, REPLACEMENT AND RETRIEVAL ACTIVITIES
- LONG DURATION (6 TO 18 MONTHS) EXPOSURE TO ON-ORBIT ENVIRONMENT

STATION SERVICES REQUIRED
- CREW 120 MAN-HOURS/YEAR (MINIMUM) TO 4900 MAN-HOURS/YEAR (MAXIMUM)
- POWER 0 1kW (MINIMUM) TO 10kW (MAXIMUM) PER MISSION
- VOLUME 160 FT^3 INTERNAL TO SS 40 FT OF STATION-ATTACHED PSA
- DATA HANDLING 10^3 TO 10^8 BPS
- SPECIAL CONDITIONS
  - LOW GRAVITY
  - SPACE VACUUM
  - INFINITE HEAT SINK
  - LONG DURATION
  - BEYOND ATMOSPHERE

Figure 4.2-10. Station-Attached NASA Technology Development

- Spacecraft less than 11.9 feet in diameter use some combination of Spacelab pallet weight trends and current spacecraft support structure weight trends for ASE.

- Spacecraft more than 11.9 feet in diameter have custom attached fittings (that are part of the spacecraft structure), based on current large spacecraft designs for ASE.

SHUTTLE TRAFFIC

The resulting Mission Scenario 6, Option 3 Shuttle traffic models are presented in Figures 4.2-11, 4.2-12, and 4.2-13 for the medium, low, and high mission models, respectively. The figures show the total traffic summarized annually and by the three destination orbit inclinations for the Space Station study years of 1991 through 2000. The low-inclination (28.5 degrees) flights represent the Shuttle traffic to the Space Station. For the medium model, these data show an average annual flight rate of approximately 20 trips to the station, with a peak of 22 flights occurring in the year 1999, and a total of 192 launches to the station for the first ten years of operation. The station requirements were determined and time phased based on these flight rates.

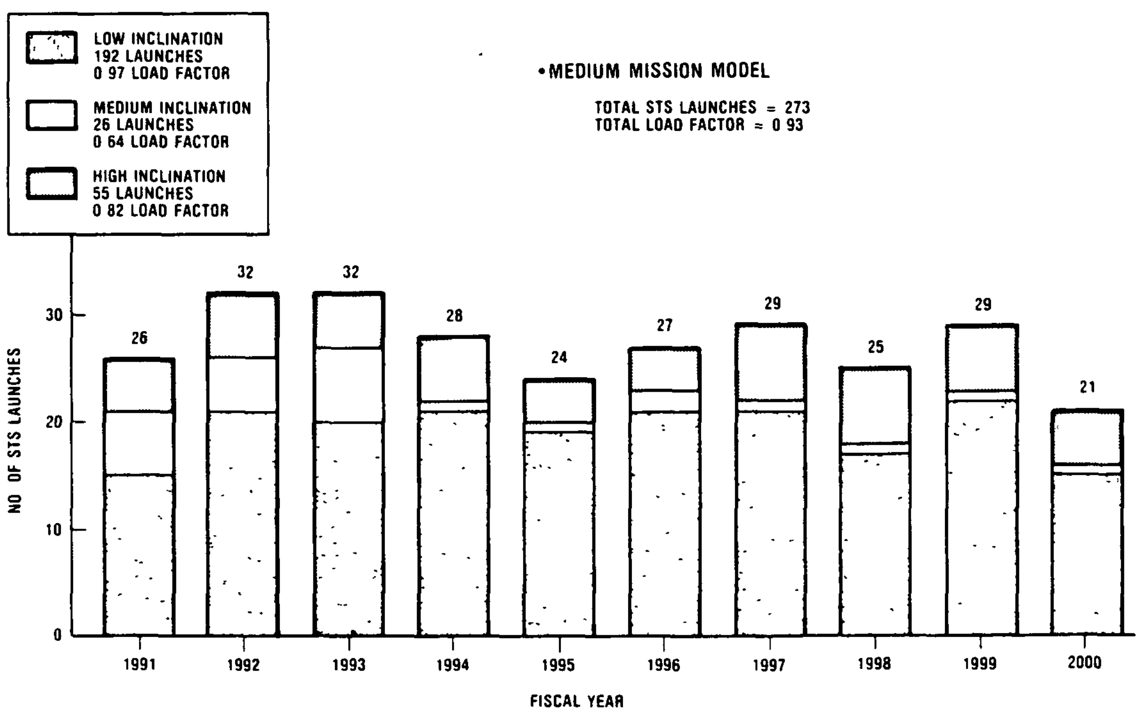


Figure 4.2-11. Option 3: STS Launch Summary, Mission Scenario 6

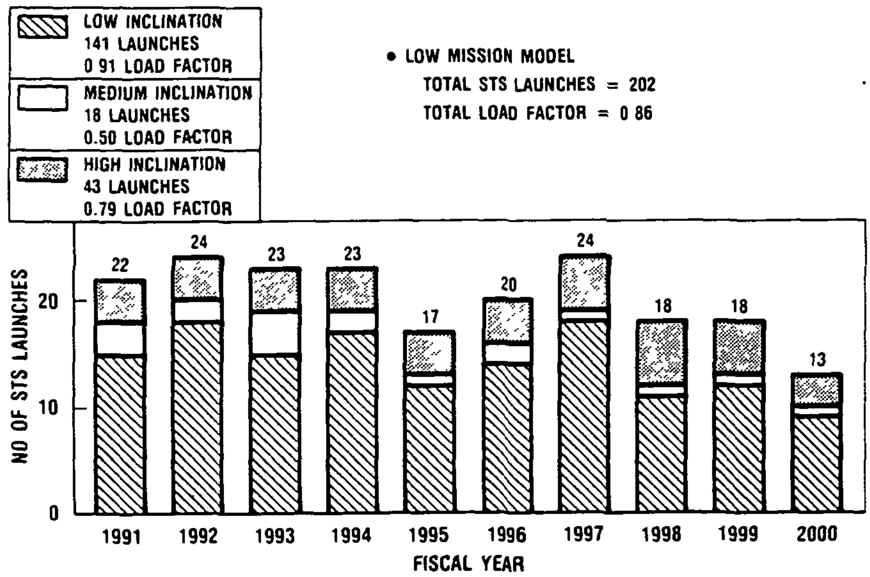


Figure 4.2-12. Option 3: STS Launch Summary, Mission Scenario 6, Low Model

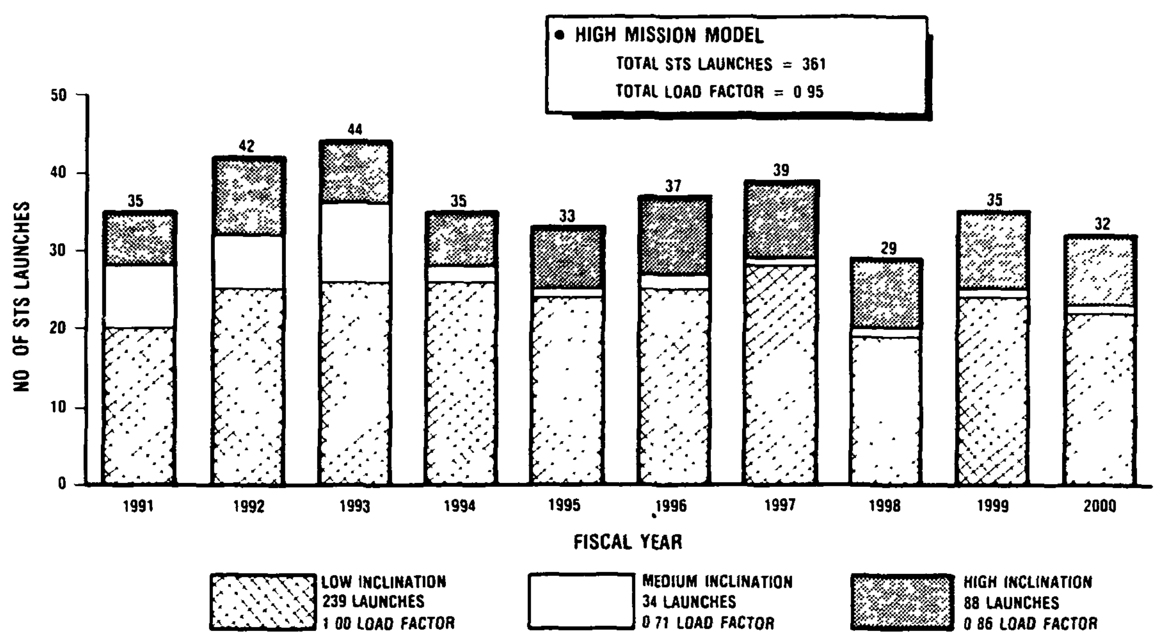


Figure 4.2-13. Option 3: STS Launch Summary, Mission Scenario 6, High Model

4.3 TIME-PHASED USER MISSION PAYLOAD SUPPORT REQUIREMENTS

The resulting time-phased user mission payload support resource requirements are presented in this section. Requirements data are presented for the following key Space Station sizing resource parameters:

- Payload mass flow processed
- Cryogenic and storable propellants
- Crew hours utilized and manning levels required
- Power consumption
- Data processing rates
- Station storage and volume interfaces

MISSION PAYLOAD REQUIREMENTS DATA

As discussed previously, the mission payload requirements data were generated by analyzing each mission payload contained in the mission model that is processed through the Space Station. Table 4.3-1 illustrates a typical missions that are either performed at, processed through, or serviced by the requirements detail established for the mission payloads. These data are assembled into a computer program that organizes the mission payloads by user mission area, station services needed, upper stages utilized, and mission class. This computer program was developed as part of the supporting studies. The mission payloads are further categorized by level of resource or services utilized. These data are then processed through a statistical summation routine that generates resource element matrices spread by mission model year. The final program outputs are plots of the total resource requirement for each parameter time phased by model year and summed by the selected service category content.

PAYLOAD MASS PROCESSED

The time-phased mass flows of the mission payloads interfacing with the Space Station are presented in Figures 4.3-1 through 4.3-3. These data represent the low inclination (28.5 degrees) and high-energy medium inclination mission that are either performed at, processed through, or serviced by the recommended baseline Space Station. Figure 4.3-1 shows the medium mission model data, Figure 4.3-2 illustrates the low mission model data, and Figure 4.3-3 shows the high mission model data. As shown, the mass flows are summarized annually, broken down by the mission area categories of national security, commercial communications, space materials processing, science and applications, and technology development. The summaries are for the user

Table 4.3-1. Payload Requirements for Space Station Resources

EXAMPLE MISSION PAYLOAD REQUIREMENTS DATA SHEET

PAYLOAD NOMENCLATURE: TD-G DATA BUS NOISE SUPPRESSION DEMONSTRATION

MISSION TYPE OPERATIONAL ☐ SERVICE ☐ CHECKOUT ☐ OTHER TECHNOLOGY DEVELOPMENT

TIME INVOLVEMENT ATTACHED 1 YEAR (8,760 HR), DETACHED ____

PAYLOAD LOCATION INTERNAL (PRESSURIZED) ____, EXTERNAL (VACUUM) PSA

PAYLOAD MASS 440 LB, PAYLOAD VOLUME (DIMENSIONS) 12 FT. X 2 FT. X 12 FT.

POWER REQUIREMENTS CONTINUOUS 0.6 KW; PEAK 1.0 KW

TIME DURATION 5 HR/DAY, TIME DURATION 0.5 HR

MANPOWER REQUIREMENTS NO. OF CREWMEN 1, HOURS/MAN ____; TOTAL 1,600

PROPELLANT REQUIREMENTS CRYO NONE KLB, NON-CRYO NONE KLB

DATA REQUIREMENTS (P/L ⟷ SS) QUANTITY 200 Gbits/DAY, RATE 80 Mbps (4 DUTY CYCLE); STORAGE 60 Gbits/ORBIT

TELECOMMUNICATIONS. DATA QUANTITY 4 Gbits/DAY, RATE 300 Mbps; STORAGE 1.2 Gbits/ORBIT

ATTITUDE CONTROL (POINTING) DIRECTION SUN ACCURACY STATION LEVEL G-LEVEL NOT CRITICAL

THERMAL CONTROL TOTAL BTUs TBD, BTUs/HOUR TBD

ENVIRONMENTAL CONTROL (LIFE SUPPORT) (LBS) O_2 NONE; N_2 NONE, H_2O NONE; CO_2 MNGMT NONE

CONSUMABLES HELIUM NONE LBS, OTHER ____

SUPPORT VEHICLES. OR EQUIPMENT *(INCLUDE SUPPLEMENTAL DATA SHEET) OTV ☐ TMS ☐ FSS ☐ RMS ☒ HPA ☐ MMU ☐ OCP ☐ EVA ☐

LAB EQUIPMENT* NONE

HOUSEKEEPING BUS (F.F.) DNA

SERVICING EQUIPMENT* NONE

CHECKOUT EQUIPMENT* INITIAL CHECKOUT FOR OPERATIONAL STATUS

OTHER (COMMENTS) MEDIUM MODEL 1994, LOW MODEL 1995, HIGH MODEL 1993, SINGLE CYCLE MISSION ONLY - NOT REPEATED

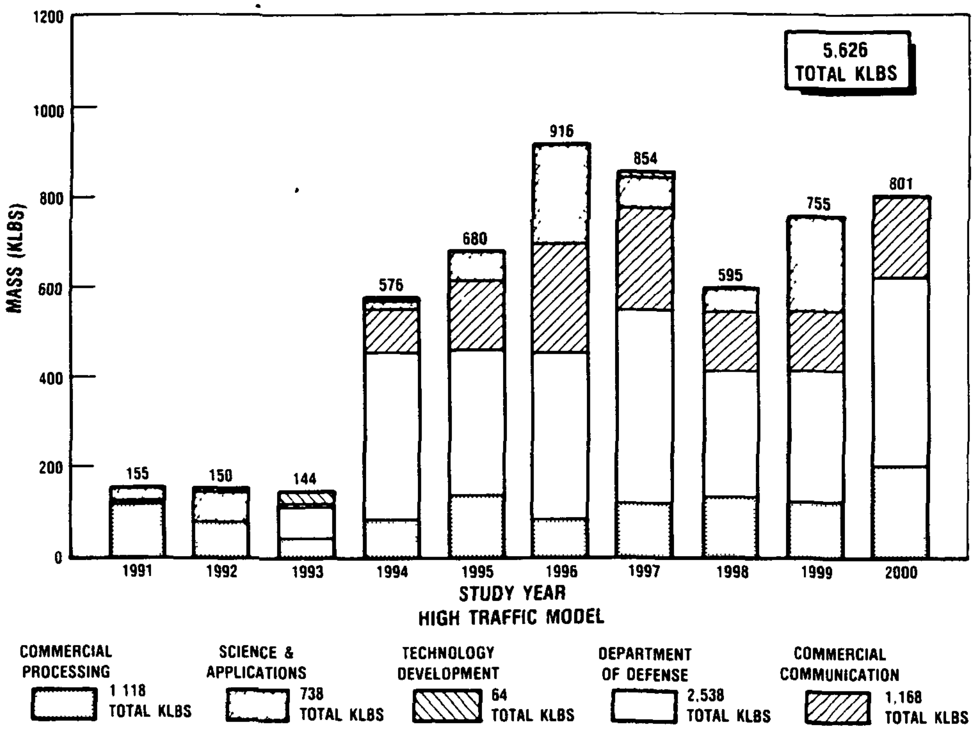


Figure 4.3-1. User Mission Payload Mass Processed

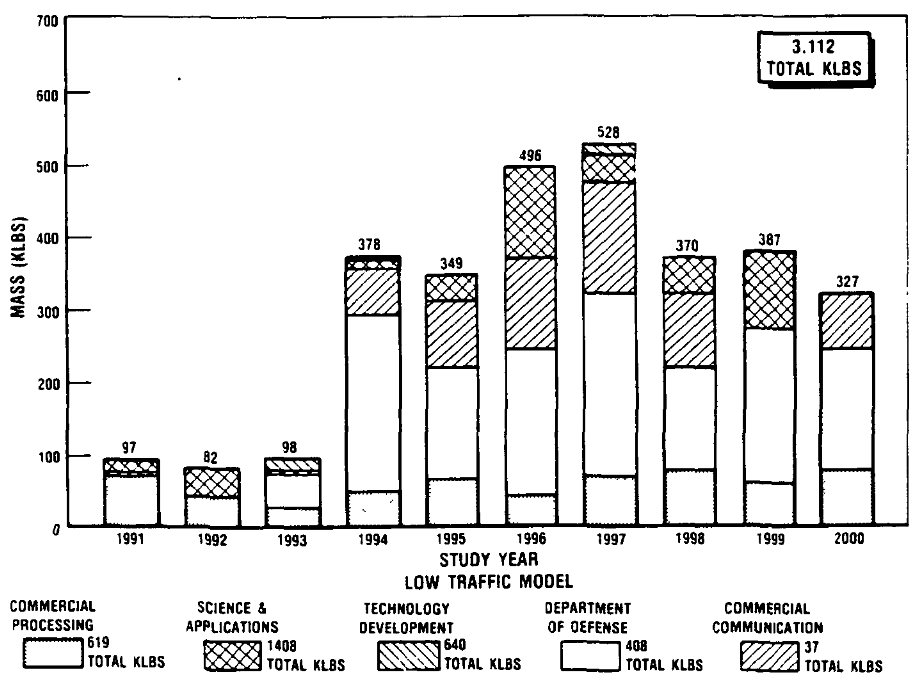


Figure 4.3-2. User Mission Payload Mass Processed, Low Mission Model

mission payload mass only and do not include upper stages, propellants, orbiter ASE, or other payload support hardware masses.

PROPELLANT REQUIREMENTS

The time-phased user mission propellant requirements are illustrated in Figure 4.3-4 through 4.3-6, for the medium, low, and high mission model levels, respectively. These data are summarized annually and by the two propellant categories of cryogenic (LO_2 and LH_2) and storable (MMH/N_2O_4). The cryogenic propellant is that used to fuel the station-based reusable PKM OTV, which is utilized to place the mission payloads destined for high-energy orbits in their transfer orbits. The storable propellant is that used to fuel the station-based TMS, the GEO-based GEO servicing TMS, and to provide propellant servicing to mission payloads such as the coorbiting free flyers. Propellant management is provided through on-board storage at the station where propellants are accumulated as they are delivered by the orbiter and then transferred to the using vehicle. The cryogenics are stored in either of two tank sets attached in tandem to one of the station docking/berthing ports, and the storable propellants are managed through a tank set located on the satellite servicing equipment pallet that is maintained in the PSA.

CREW HOURS REQUIREMENTS

Crew man-hours estimates were developed for the on-orbit mission support activities to assist in studies of crew habitation sizing, cost estimates, and, for orbiter-only operations, as a method of assessing feasibility of certain cargo bay manifests. These estimates were largely based on computer-prepared tables listing each function to be accomplished for handling and processing representative payload elements (and related stages when used to carry the payloads to orbits distant from the parent vehicle). Each function (task) listed was accompanied by time estimates, number of crew, and resulting crew-hours. The computer output summed time and crew-hours for each mission analyzed. Then these data were compiled on a year-by-year basis.

The crew-hours estimates for high-energy missions (to GEO, to planets, or involving significant plane changes) were closely related to weight of the prime payload satellite (excluding apogee kick motors or other attached upper stages). The rationale for this approach was that complexity of checkout and selected handling operations is approximately proportional to weight and that crew-hours of effort for these tasks are approximately proportional to complexity. However, certain handling operations (such as unloading from orbiter, cryo fueling, separation, and monitoring at on-orbit launch) are nearly constant, or related to manifesting advantages of several payloads on one OTV. For example, if three small payloads are staged on a single OTV flight to GEO, then the crew-hours for OTV-related handling functions were divided by three. After a group of representative missions was analyzed, a graph of crew-hours versus payload weight (as shown in Figure 4.3-7) was prepared for further estimates of high-energy missions' crew-hour requirements.

Figure 4.3-7 indicates that a significant advantage in crew-hours reduction was afforded to missions with planetary destinations because no hours were charged for return and servicing of the reusable OTV (it was

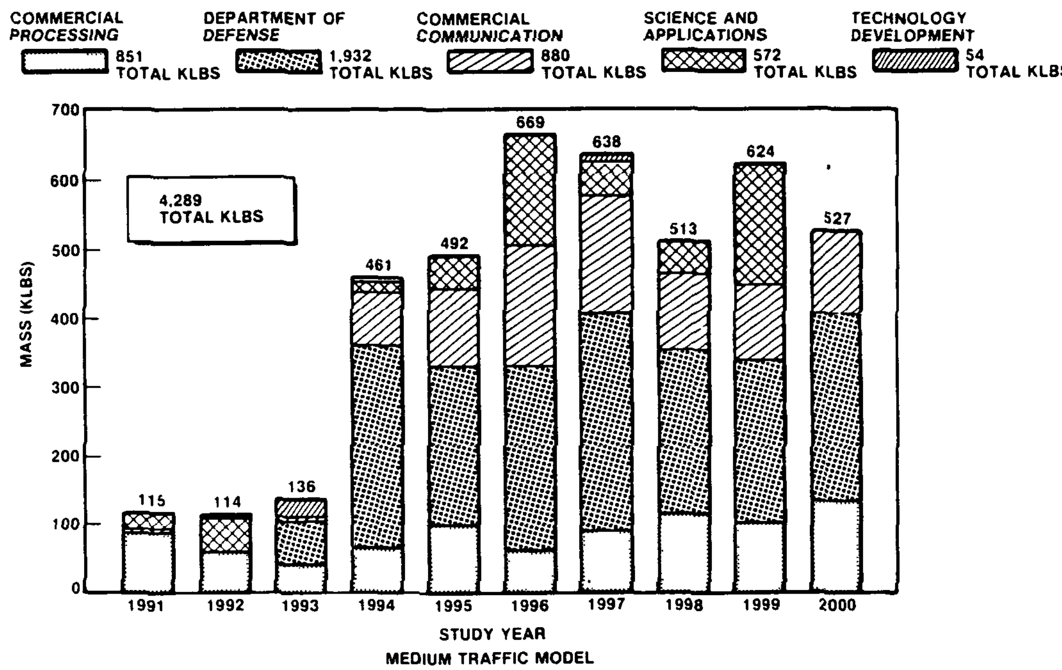


Figure 4.3-3. User Mission Payload Mass Processed, High Mission Model

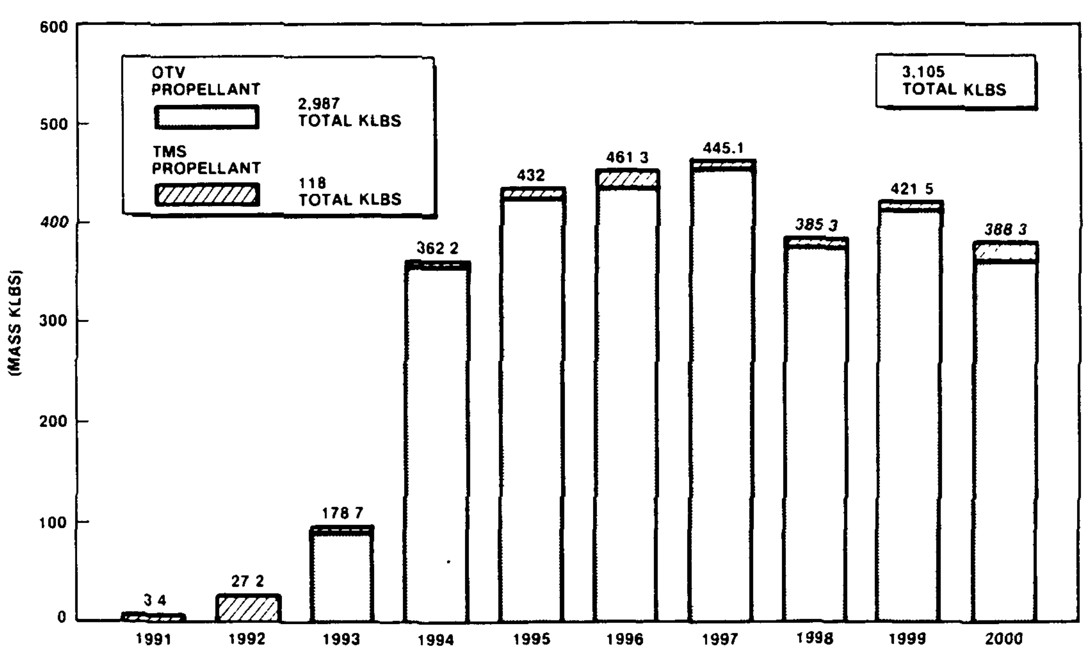


Figure 4.3-4. User Mission Propellant Requirements

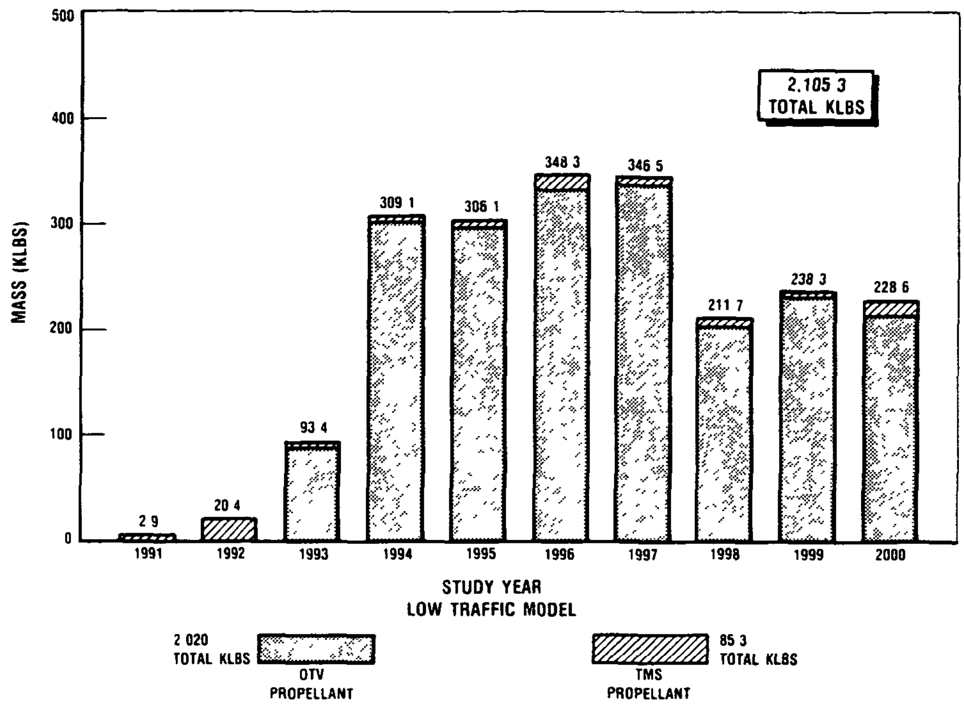


Figure 4.3-5. User Mission Propellant Requirements, Low Mission Model

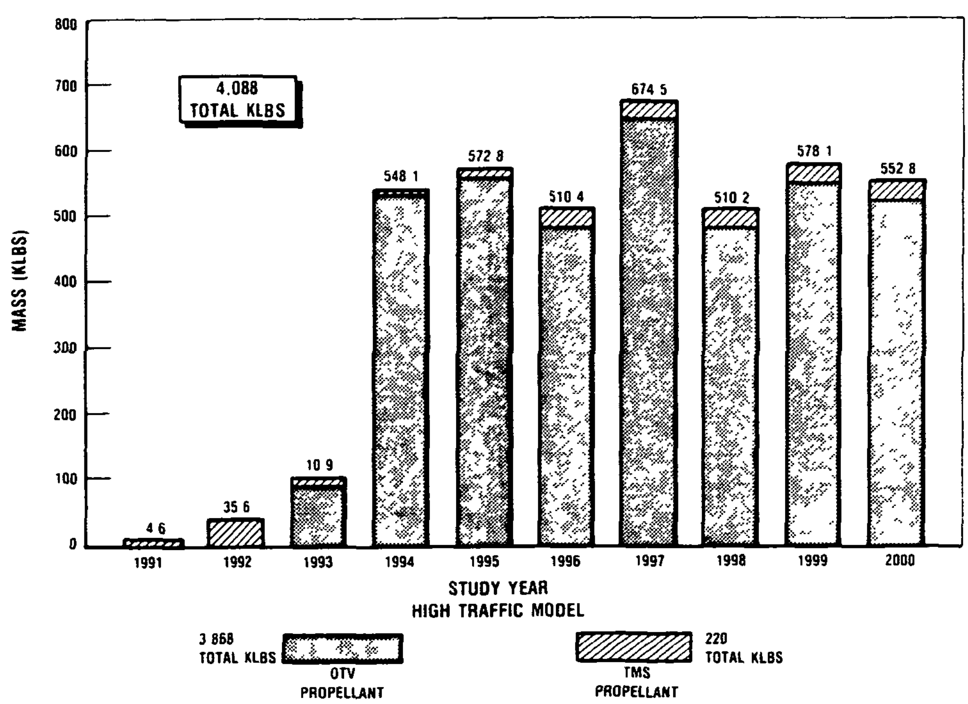


Figure 4.3-6. User Mission Propellant Requirements, High Mission Model

considered to be expended on these missions). The figure also shows that fewer hours were needed for launches of such missions from the orbiter (lowest graph line). The reason for these lower on-orbit crew-hours is that the mating, assembly, and fueling was presumed to be performed on the ground prior to flight.

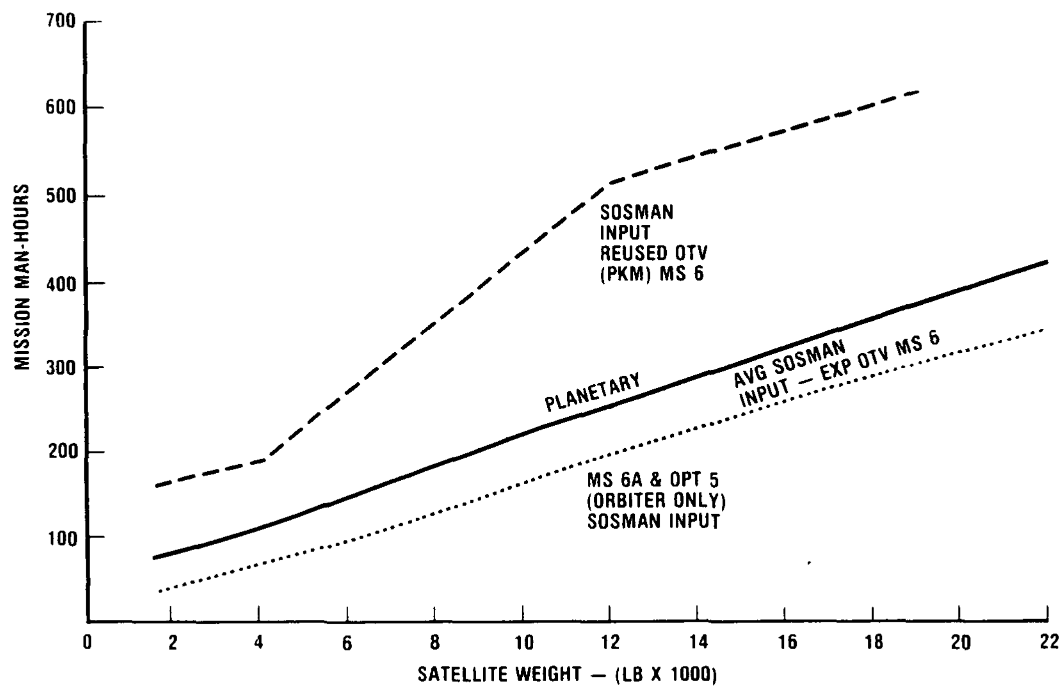


Figure 4.3-7. DOD High-Energy Satellites and Communication Satellite Manhours, Estimates by Weight Class

Estimates of crew-hour requirements for low earth orbit missions consisted of two major components: handling and processing of payloads and operations (experiments and materials processing). The crew-hours for the operations were estimated on a level-of-effort basis, related to the assumed level of automation. For those free-flying satellite missions involved in delivery, servicing or retrieval by the teleoperator maneuvering system (TMS), some benefits were achieved by manifesting two or more mission payloads on one TMS flight from the Space Station (or orbiter where appropriate).

Because many of the crew-hours estimates were first compiled in small functional elements, they could be analyzed according to several types of categories. Among these were user types (commercial communications, DOD, commercial space processing, and NASA R&D) and types of services (assembly check-out, launch, retrieval, and service).

Overall summaries by year were performed to compare labor requirements to labor availability, based on an assumed ten-hour day, six days per week. Housekeeping charges of 25 percent for the initial station (one out of four men), and 12.5 percent (one out of eight men) for the growth station were assumed in order to size the station average habitation requirements. These assumptions are discussed further in the facility requirements sections. Housekeeping is herein defined as distribution of logistics supplies, station-related maintenance and updating, crew interchange, operations of solar arrays, orbit makeup, power switching, etc. All estimates shown deal only with on-orbit activity and do not include orbiter crew time for ascent or descent, even in the orbiter-only cases that were analyzed.

The resulting time-phased user mission requirements for Space Station-based crew hours are summarized in Figure 4.3-8 through 4.3-10, for the medium, low, and high mission model levels, respectively. These data are summarized annually and by the user mission area categories of national security, commercial communications, space materials processing, science and applications, and technology development. From these summaries the equivalent crew size necessary to provide the crew-hour requirements can be determined. The equivalent crew is based on the baseline of each crew member working ten hours per day, six days per week yielding 3,120 working hours per year. These data are indicated in the integrated requirements discussion continued in Section 4.5.

POWER REQUIREMENTS

The time-phased user mission payload Space Station power consumption requirements are presented in Figures 4.3-11 through 4.3-13 for the medium, low, and high mission model levels, respectively. These data are presented in the same breakdown as the payload mass and crew hours requirements for the typical year of 1997. The mission power data were computed considering average continuous or long-term power service required for the duration of the payload's interface with the station, and for the typical duty cycle for attached and integral mission payloads. In addition, significant nominal time duration peak power loads, such as the 10 kW, one-hour requirement to load the OTV LH_2 or LO_2 tanks, were accounted for. For the purpose of this study, short-term peaks or transients were not factored in. This is an area that will be addressed in the continuing Space Station studies at Rockwell.

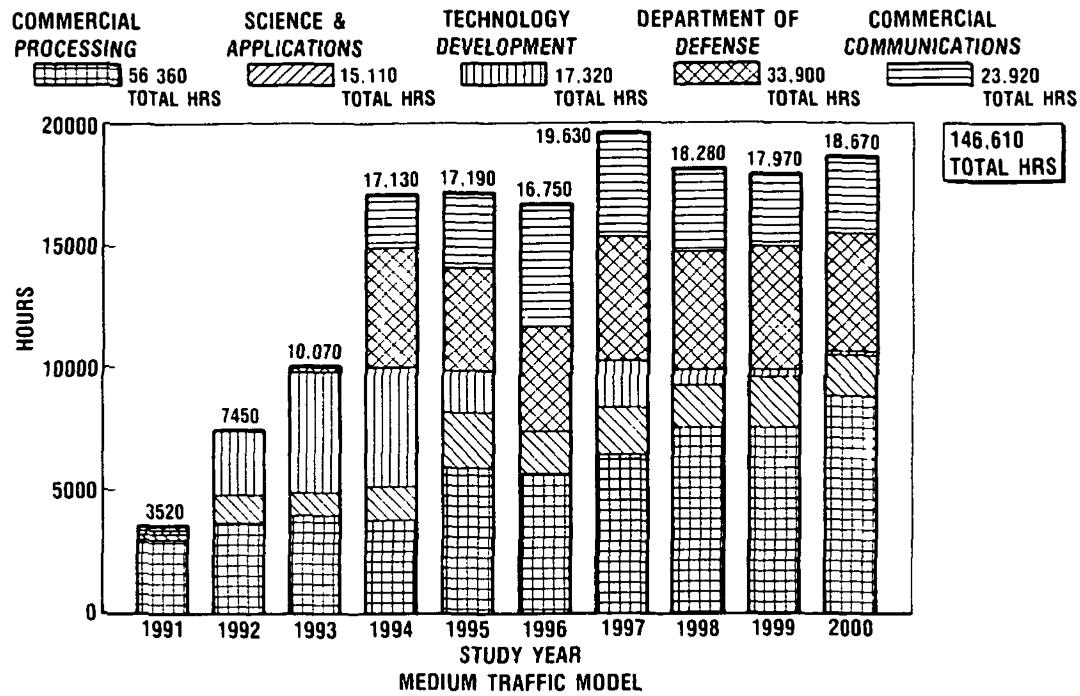


Figure 4.3-8. User Mission Payload Crew Hours

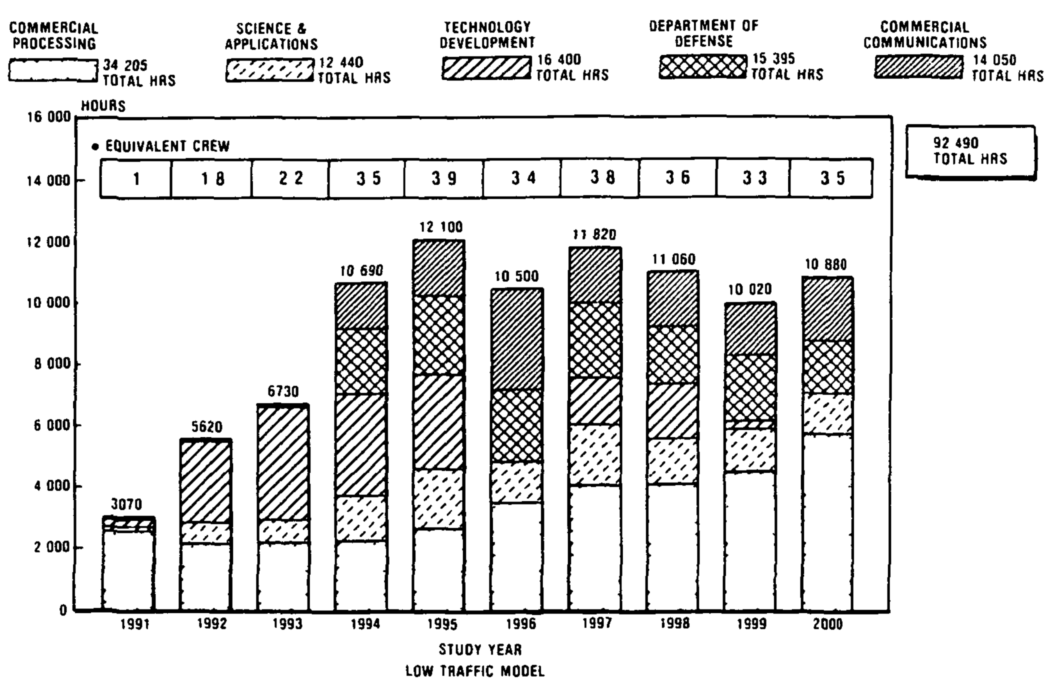


Figure 4.3-9. User Mission Payload Processing Crew Hours, Low Mission Model

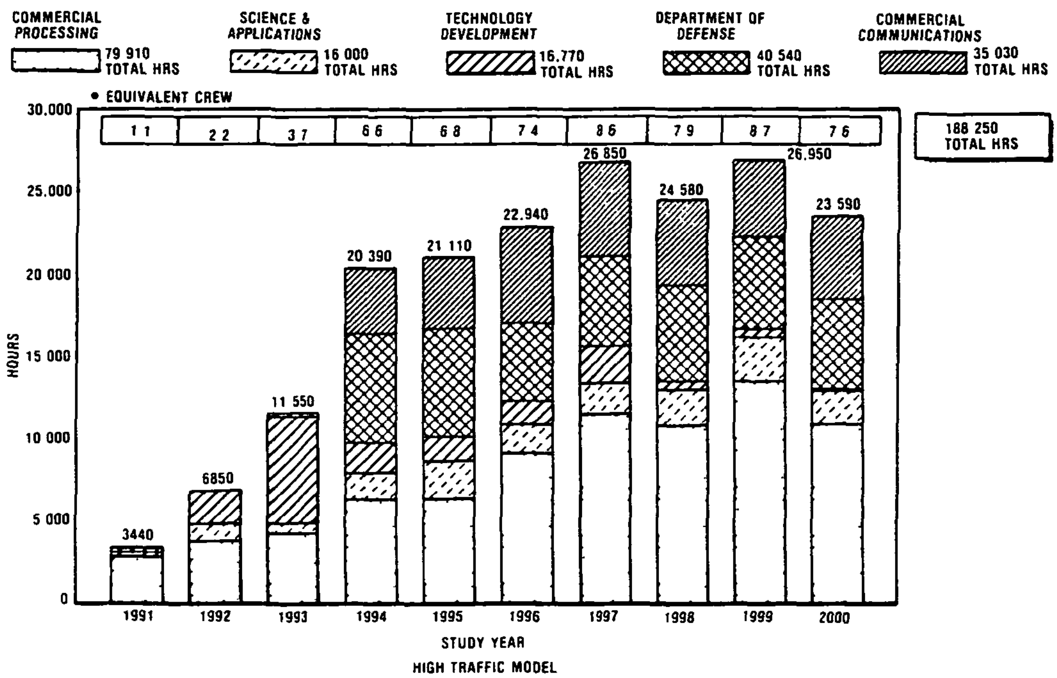


Figure 4.3-10. User Mission Payload Processing Crew Hours, High Mission Model

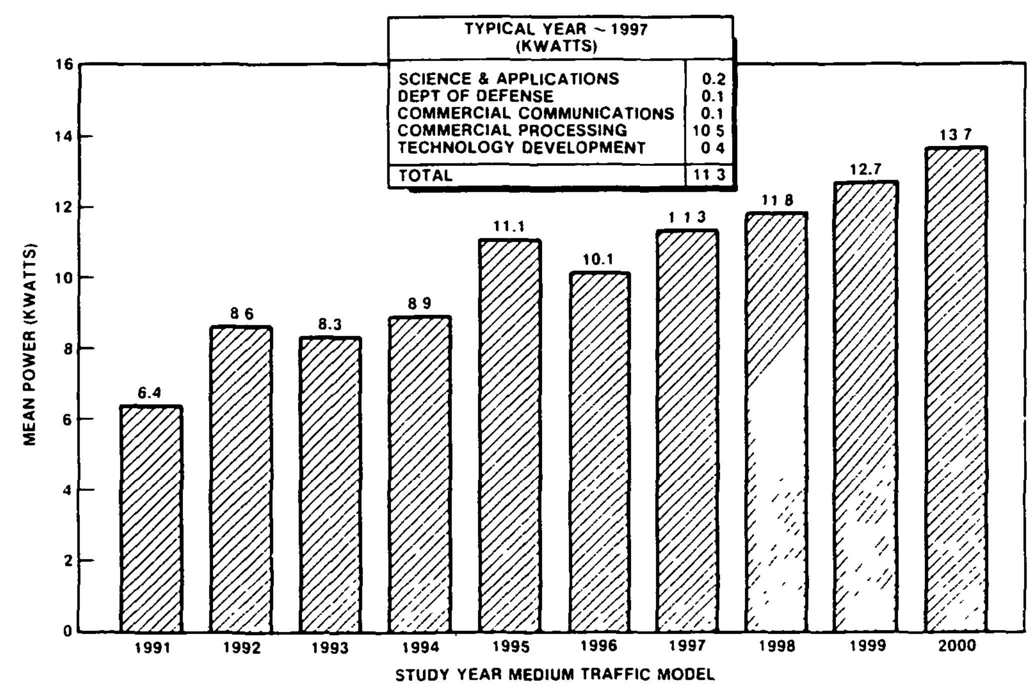


Figure 4.3-11. User Mission Power Requirements

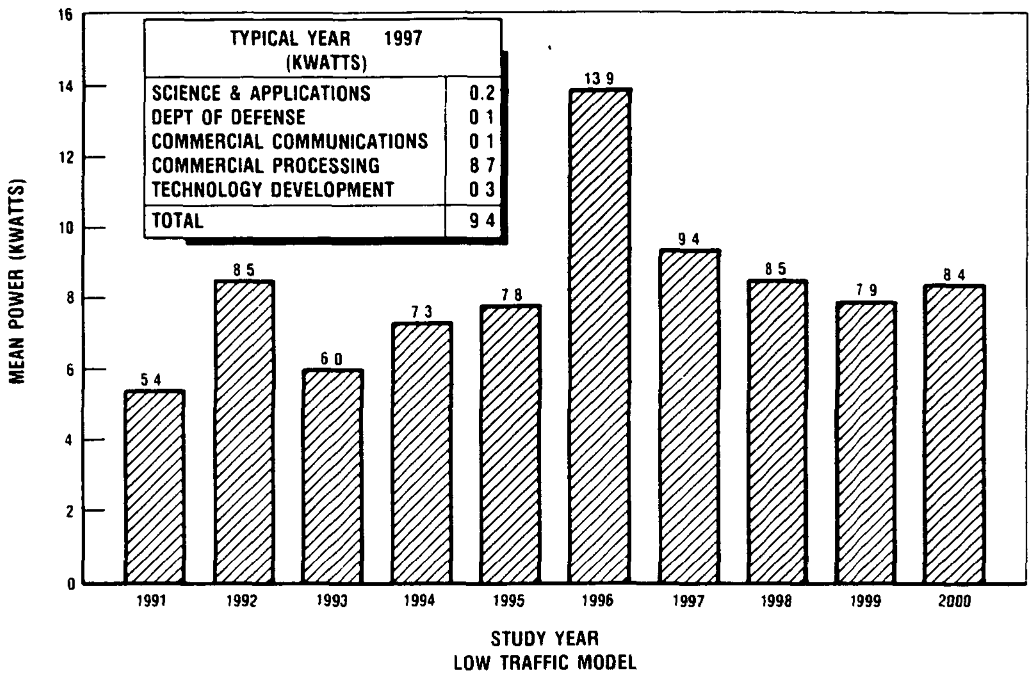


Figure 4.3-12. User Mission Payload Processing Power Requirements, Low Mission Model

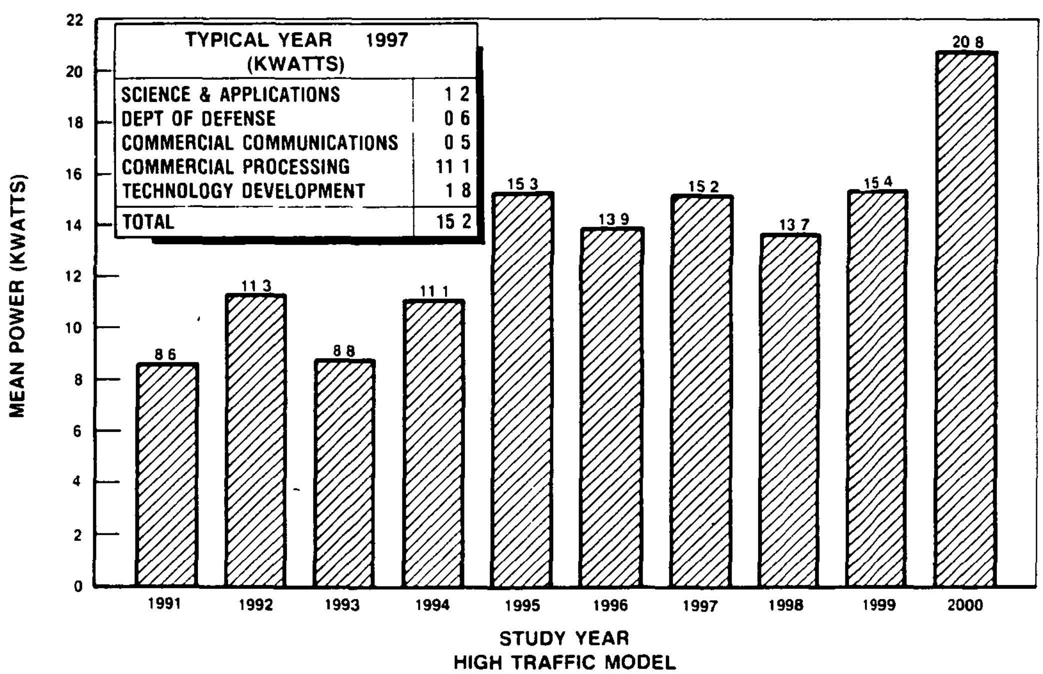


Figure 4.3-13. User Mission Payload Processing Power Requirements, High Mission Model

DATA PROCESSING REQUIREMENTS

The time-phased user mission payload data processing requirements are shown in Figures 4.3-14 through 4.3-16 for the medium, low, and high mission models, respectively. For the typical year of 1995 these data are presented in the same breakdown as the payload mass, crew hours, and power requirements. The parameter summarized is total raw data generated per station orbit by the user-mission payloads that must be received by the station, processed, and transmitted to the ground. The process of data handling, data reduction and compression, and downlinking is discussed in the station facility requirements section. The raw data rates were calculated by analyzing the data rate generation and communication design levels, in addition to the duty cycles of the user-mission payloads on a per orbit basis. These data were then related to the 92-minute station orbit to obtain data quantities for each station orbit and subsequently summarize the data quantity.

DIMENSIONAL VOLUME REQUIREMENTS

The time-phased user mission payload dimensional length requirements for interfacing with the station payload service fixture are illustrated on Figures 4.3-17 through 4.3-19 for the medium, low, and high mission models, respectively. These are one of the classes of working, storage, and processing space and facility interfaces that impose requirements on the station from the user-mission payload flow through the Space Station. These requirements affect the station's internal and external architecture and can be segregated into three class areas. These areas are mission payloads attached externally to the PSA, mission payloads attached externally to the station docking and berthing ports, and mission payloads or labs worked internally within the station modules.

The PSA-attached payloads are typically free-flying satellites that are checked out and integrated with the OTV at the station for transfer to high energy orbits, or free-flying satellites that are brought to the station for servicing or interfacing with the TMS. The requirements for these missions are illustrated as the product of payload length and stay time, which is checked against the payload-length days available annually in the three PSA payload processing and storage volumes. Since all mission payloads and equipment items arrive at and are first attached to the PSA from the orbiter cargo bay, the orbiter's 15-foot diameter can be factored out of the volume numbers and payload length can be used to determine the requirements for station sizing. The resulting length (Figure 4.3-17) requirements are time-phased annually and broken down by the user mission categories of national security, commercial communications, space processing, science and applications, and technology development.

The payloads attached externally to the docking and berthing ports are typically the specially designed science and applications pressurized laboratory modules, the cryogenic propellant storage tank sets, station-attached mission payloads, and free-flying satellites stored at the station. These requirements are summarized annually by the content of the mission areas listed above. Also, the total port-days required per year, resulting from the product of mission payload port usage and payload duration at the station, are summarized.

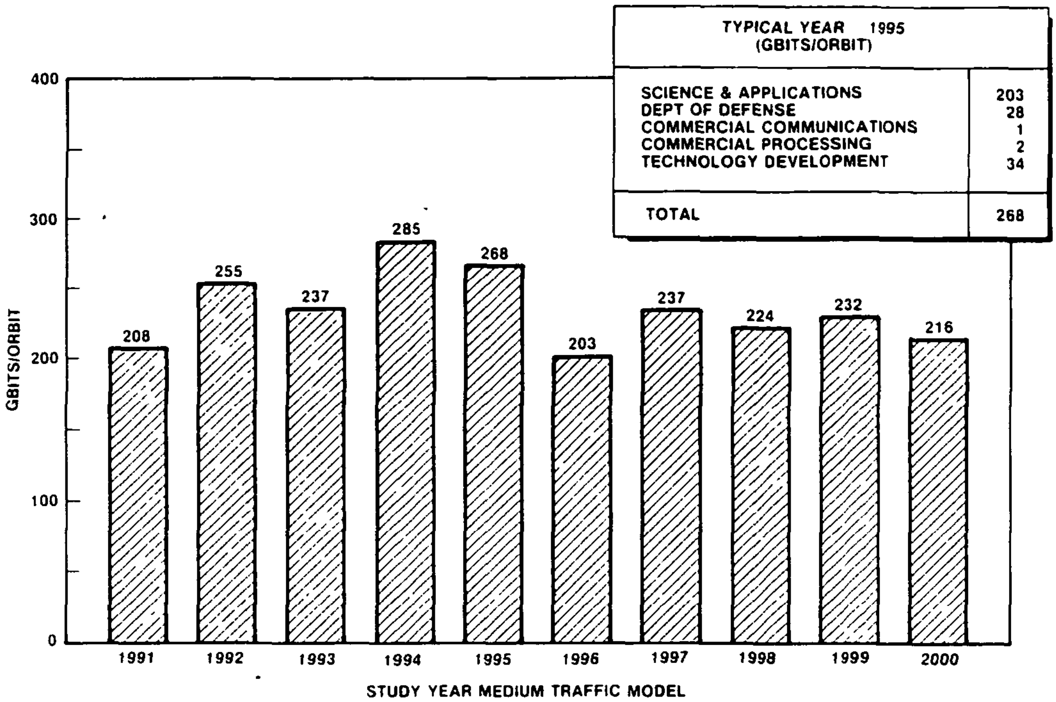


Figure 4.3-14. User Mission Data Processing Requirements

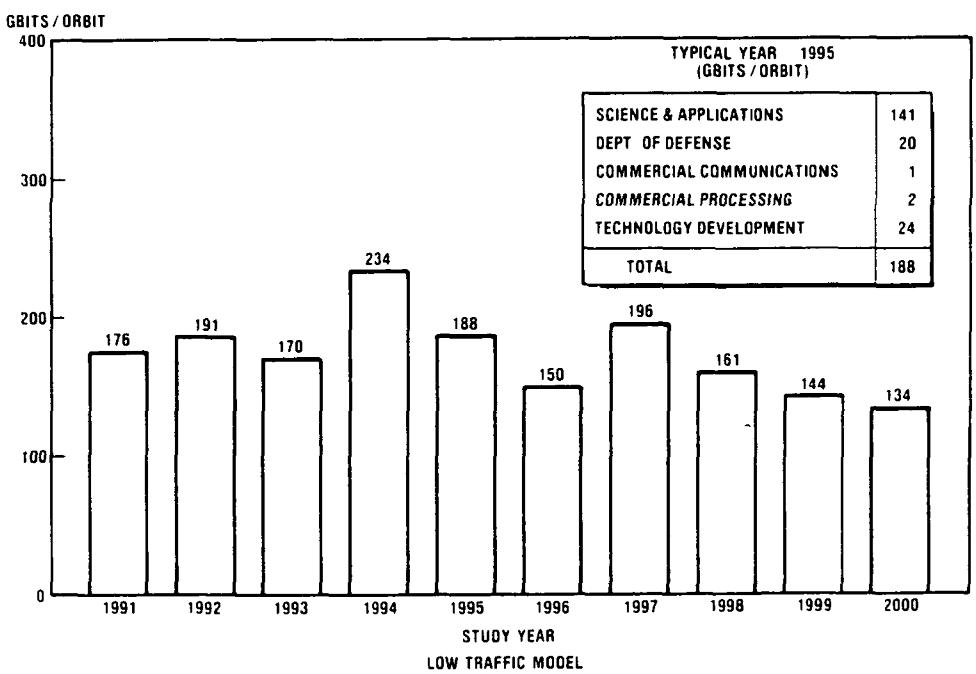


Figure 4.3-15. User Mission Data Processing Requirements, Low Mission Model

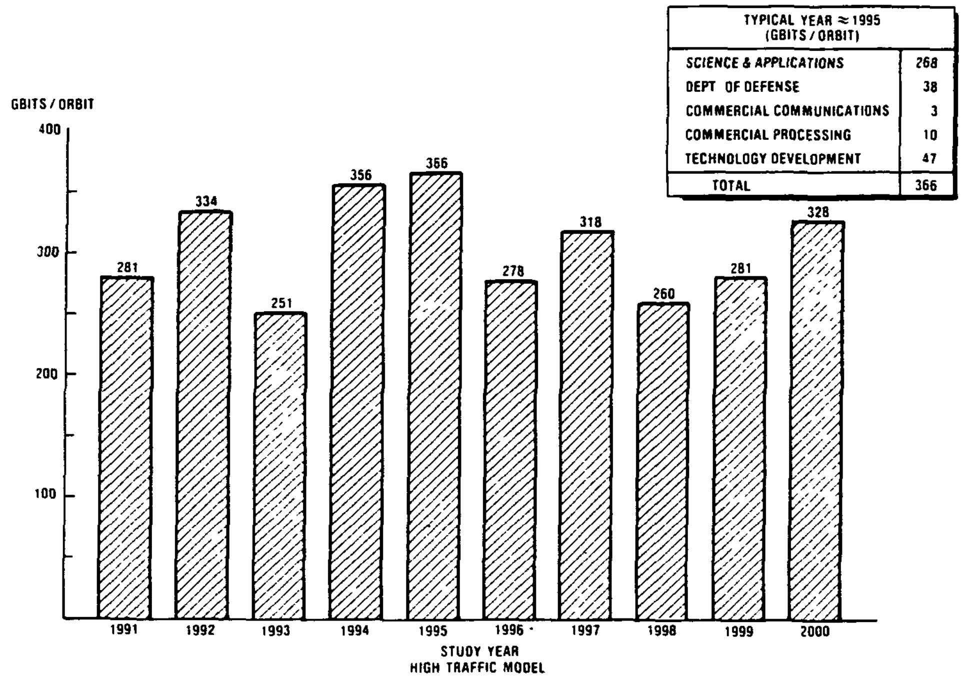


Figure 4.3-16. User Mission Data Processing Requirements, High Mission Model

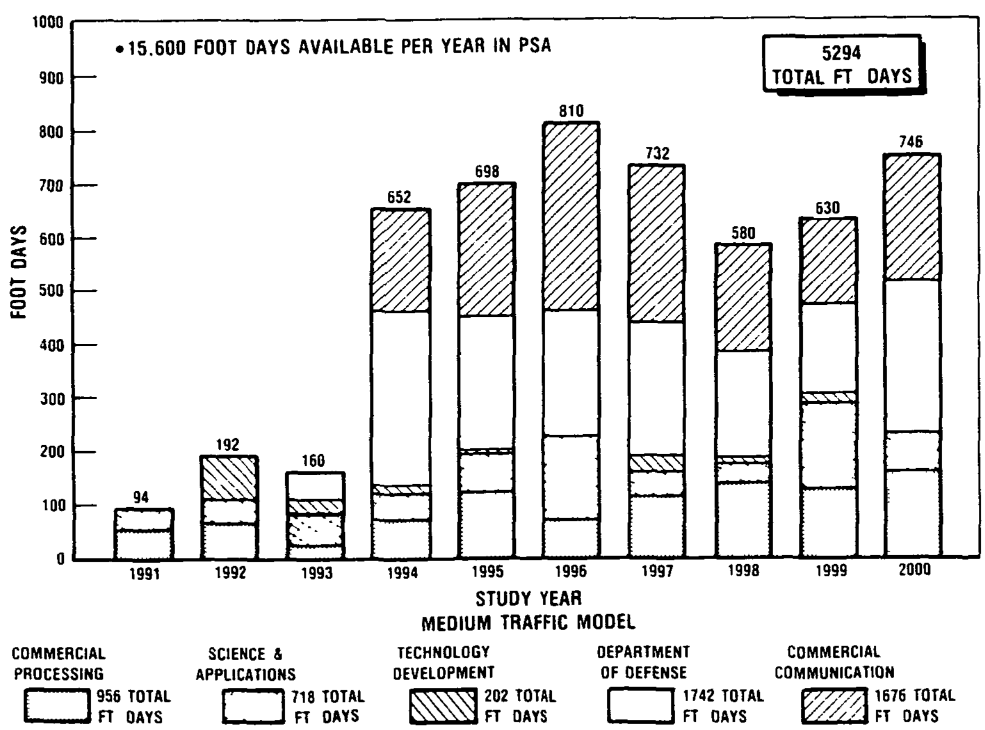


Figure 4.3-17. Payload Service Assembly Requirements

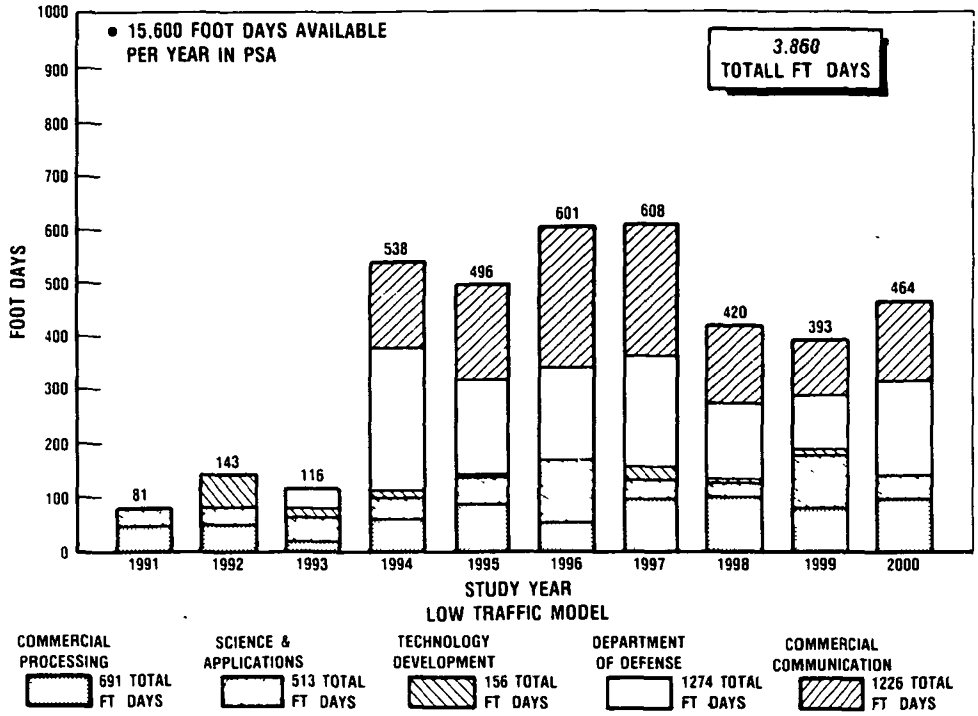


Figure 4.3-18. User Mission Payload Dimensional Volume Requirements, Low Mission Model

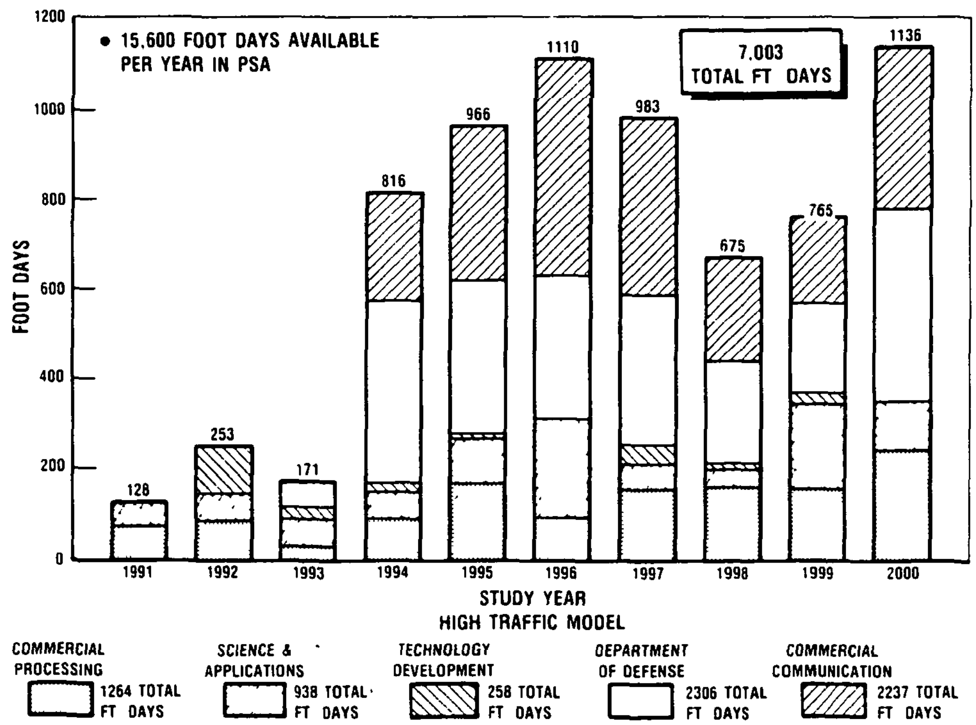


Figure 4.3-19. User Mission Payload Dimensional Volume Requirements, High Mission Model

The internal and integral mission areas are the designated laboratories, such as the life sciences lab and the specialized small lab, and mission equipment appropriate for internal operations. Since this mission area is small and tends to be long duration, these requirements are listed in tabular format.

4.4 SPACE STATION FACILITY REQUIREMENTS

To develop the total Space Station integrated system and subsystem requirements, the station facility requirements are discussed in this section. As opposed to the mission payload support requirements presented in the previous sections, the facility requirements are defined as those system and subsystem resource levels necessary for general operations and stationkeeping that are not identified against a specific mission payload or mission area. Scheduled or unscheduled station maintenance and repair activities using crew hours is an example of a facility requirement. The recommended station architecture is the Option 3 program that specifies an initial station with a four crew member capability evolving to a growth station with an eight crew member capability. The IOC of the initial station is targeted for 1991, and the full operational capability of the growth station is targeted for 1994. Consequently, the facility requirements are shown for the two levels of operational capability (initial and growth).

The facility requirements presented herein resulted from supporting system and subsystem trades and analyses directed toward a baseline architectural definition that could be utilized for further study. The major requirements and guidelines that influenced the initiation of these trades and guided the selections for the initial and growth baseline Space Stations were those outlined by NASA for the space operations center (SOCO and the science and applications manned space platform (SAMSP). However, many of the requirements were changed or deleted as the studies progressed and the user-verified mission models developed.

ELECTRICAL POWER REQUIREMENTS

The Space Station electrical power subsystem (EPS) provides power to all subsystems and mission support functions and activities. For the Space Station program, the electrical power requirements at the bus load are at least one order of magnitude greater than the present-day spcaecraft design. A revolutionary optimum EPS design has to be reached to meet all the stationkeeping and payload support activity requirements. The EPS design driver is the 200 to 243 nautical miles altitude orbit period of 92 minutes, of which the Space Station is eclipsed by the earth for 36 minutes. The average facility power requirements under these conditions are 14.5 kW for the initial station and 35 kW for the growth station. The distribution of these requirements to subsystem loads is shown in Table 4.4-1.

CREW REQUIREMENTS

The facility crew hour expenditures for the aggregate of typical tasks such as maintenance, logistics distribution, compilation of station logs, routine planning and housekeeping, and system health and status reporting are shown in the baseline development studies to be equivalent to one crew member out of the four manning the initial station, and one crew member out of the eight manning the growth station. With the evolutionary development of the growth station from the initial station, the learning process as procedures and operations become standardized is expected to reduce the crew

Table 4.4-1. Baseline Space Station Facility Electrical Power Loads

LOAD	AVERAGE LOAD FOR 92 MIN ORBIT~ WATTS	
	INITIAL STATION	GROWTH STATION
• ECLSS	3,700	13,600
• COMM / DATA MANAGEMENT	4,000	5,140
• PROPULSION SYSTEM (HEATERS)	100	200
• THERMAL CONTROL SYSTEM	1,500	4,020
• ATTITUDE CONTROL	250	600
• LIGHTING & INSTRUMENTATION	1,800	3,600
• CREW ACCOMMODATIONS	1,600	4,400
— SUBTOTAL	12,950	31,560
• CONTINGENCY (10%)	1,550	3,440
TOTAL	14,500	35,000

hour tax for facility operations. Therefore, the enveloping requirement of one equivalent crew member being devoted to facility tasks is constant for both the initial and growth stations.

STATION STORAGE INTERFACES

Station storage interface requirements have been characterized for the three categories of volumes utilized. These are integral missions internal to the basic pressurized modules of the station, mission payloads or lab modules attached to docking ports, and mission payloads attached externally to the payload service assembly (PSA). Definition of the volumes devoted to facility requirements for these areas is not as straightforward as for the other system and subsystem areas because of the preliminary nature of the mission payload and laboratory hardware, as well as the station system and subsystem detail equipment volumes. In general, however, the approach, given the modular nature of the station concepts, is that the system architecture will provide the volume and storage interfaces required for facility and user mission items.

For the initial and growth stations (except for small volumes devoted to user electronic and laboratory equipment), the core pressurized modules are utilized for facility requirements. These modules are the energy module, command module, and habitability modules. The only facility requirement for the tunnel module is to provide a second exit from each major volume for the growth station. Consequently, the major portion of the tunnel module is

available for user mission activities, and in the Option 3 baseline growth station the tunnel module is utilized for a life sciences laboratory.

The facility requirements for pressurized docking and berthing port interfaces with the baseline station modules are summarized in Table 4.4-2. As shown, there are 16 ports on the initial station of which 12 are needed for the facility requirements listed. The remaining four are available for user mission pressurized modules, or unpressurized pallets and payload storage. The corresponding numbers for the growth station show 15 out of 23 ports assigned to the facility and 8 ports available for user mission requirements. In addition, there is one unpressurized port available at the end of the PSA for user missions and, as a contingency, the orbiter berthing port not being employed by the orbiter is available for temporary storage of user mission payloads.

STATION POINTING AND STABILITY

Table 4.4-3 identifies the baseline station attitude control subsystem performance capabilities. These capabilities are the same for the initial station and the growth station and are the same capabilities available to the mission payloads. Any mission payloads attached to the station that require fine pointing must employ fine pointing devices such as the Shuttle technology instrument pointing system (IPS).

The Space Station contains low-level disturbances that can impact some payload operations that require very low g levels (such as some materials processing experiments). Some typical bounds for the disturbance levels from various sources are given in Figure 4.4-1. They are based on the current Rockwell station architectural baseline configuration and represent reasonable worst-case conditions. They include rotational and translational responses to the various disturbance sources.

The aerodynamic and gravity gradient disturbances are small and relatively constant over reasonable time periods. The propulsive disturbances can generally be controlled by scheduling RCS firings and payload operations so that they don't occur simultaneously. The dominant remaining disturbance source is the crew motion. The crew motion disturbance effects can be reduced by a factor of approximately three through judicious location of payloads. Also, the crew may constrain their disturbance motion levels for varying amounts of time. An estimate of this relationship is given in Table 4.4-4.

The disturbance levels of Figure 4.4-1 may be employed as guidelines. However, if the crew disturbance levels exceed the requirements of a given payload, it is prudent to examine the situation further. The crew disturbances are periodic with predominant harmonic content in the region of a few hertz. Hence, the vibration attenuation that occurs naturally or intentionally in either the station structure of payload operational equipment can reduce these levels by orders of magnitude. In some situations, the intentional introduction of vibration attenuation devices can be accomplished quite simply. The

Table 4.4-2. Baseline Space Station Facility Pressurized Docking Part Requirements

PRESSURIZED PORT USAGE	INITIAL STATION	GROWTH STATION
SOLAR ARRAYS	2	2
RADIATOR	1	1
AIRLOCKS	2	2
ORBITER BERTHING	2	2
LOGISTICS MODULE	1	1
CRYOGENIC PROPELLANT STORAGE	1	1
PAYLOAD SERVICE ASSEMBLY	1	1
STATION MODULE INTERCONNECTIONS	2	5
TOTAL FACILITY PORT REQUIREMENT	12	15
TOTAL PORTS AVAILABLE	16	23
USER MISSION PORTS AVAILABLE	4	8

Table 4.4-3. Baseline Station Payload Pointing Requirements

SPACE STATION	AVAILABLE TO MISSION PAYLOADS
SPACE STATION POINTING ACCURACY ±5° BODY AXIS RELATIVE TO REFERENCE AXIS ±0.3° CONTROL AXIS RELATIVE TO REFERENCE AXIS SPACE STATION BODY STABILITY 0.005°/SEC (NORMAL ATTITUDE HOLD OPERATIONS)	SAME AS SPACE STATION

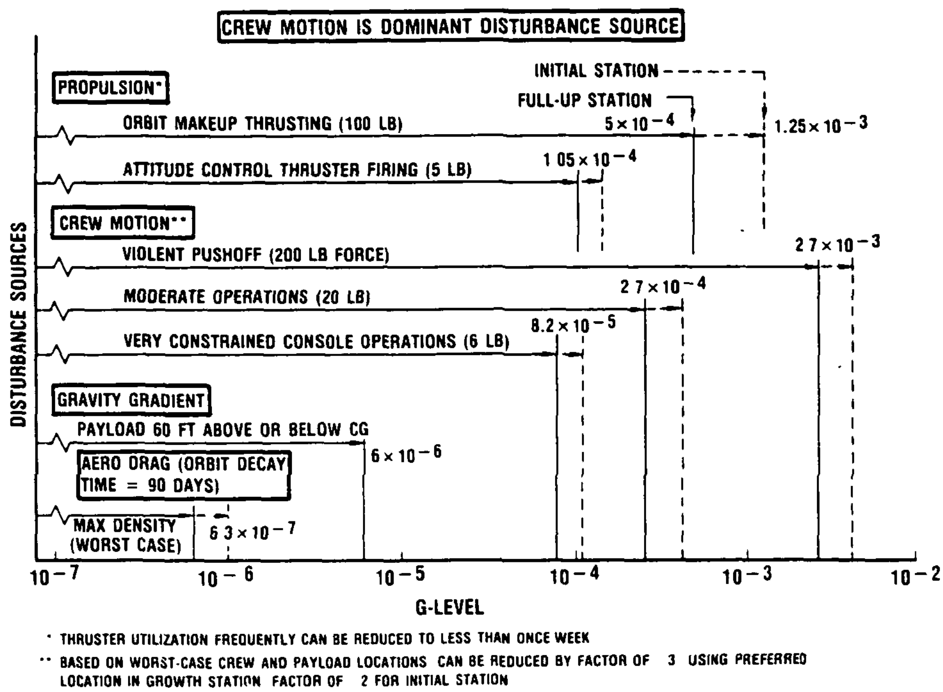


Figure 4.4-1. Space Station Disturbance Levels

Table 4.4-4. Typical Maximum Duration for Constrained Crew Operations

CREW REACTION FORCE (LB)	TYPICAL MAXIMUM CONSTRAINT DURATION (HR)
1	1
6	8
20	24
200	504 (3 WEEKS)

crew disturbance levels employed herein are based on the footnote reference* whose data can also be employed to more closely assess the payload sensitivity to crew motion disturbances.

PROPELLANT STORAGE

With the station initial and growth baseline architecture of closed ECLSS and fuel cell systems, the facility requirements for cryogenic (LH_2 and LO_2) propellant storage are only for the RCS system. These requirements are trivial compared to the user mission requirements for OTV propellants. The total RCS facility propellant storage requirements for the initial and growth stations based on a 60-day resupply and a 6:1 mixture ratio are as follows:

- Initial Station - 645 lb
- Full-up Station - 1,035 lb

As can be seen, these propellant storage requirements are extremely small compared to the 108,000 pound storage tank capacity designed for OTV propellant management.

There are no facility requirements for storable monopropellants or bipropellants. All storable propellant usage is for user mission requirements, such as TMS operations and satellite servicing. These propellants are stored in a pallet-mounted tank set located in the PSA.

DATA PROCESSING REQUIREMENTS

The data processing function is a subset of the station information management system (IMS) and is organized as the communications and tracking (C&T) system. The general requirements of the C&T system are to provide communications and data transfer on-board the Space Station (internal), provide communications from the Space Station to the ground and to other space vehicles (external), and to track various space objects for docking and other close proximity operations. The operational requirements developed are driven from the mission objectives of the Space Station architecture and are further defined to determine C&T system architecture and hardware designs in the supporting studies. These requirements are determined from other systems on the Space Station and will affect the capabilities of other Space Station elements.

Ranging, tracking, and navigation requirements of close proximity vehicles and objects may be found in the guidance, navigation, and control (GN&C) system studies. It is baselined that the primary method of determination of these data will be via navigation data obtained from GPS receivers and processors on board the buzzing bees (relayed via the

*"*Handbook on Astronaut Crew Motion* Disturbances for Control System Design," M. Conlon Kullas, NASA Reference Publication 1025, May 1979.

communications links). A backup UHF radar on the Space Station may be used for vehicles without GPS receivers, communication links to Space Stations too small for ground-based radars, or for better accuracy than ground-based radars can provide. There is a variety of types of information required to be handled by the C&T system as shown in Figure 4.4-2. All of these data types must be integrated for internal distribution to the appropriate users or transmitted to external points (i.e., the ground or other space vehicles). Figure 4.4-3 shows the various external communications and tracking interfaces. The primary requirements of the C&T system are to handle a given capacity (i.e., data rate) to each object with a specific performance and availability. Reliability of the system must be considered in determining the availability of the links in the system design but has not yet been analyzed since hardware design has not yet been determined. However, RF power margins have been analyzed with a minimum of 3 dB allotted.

The resulting principal facility requirements for the C&T system can be summarized as data rate, as all information will be transmitted and received from external sources in digital form, and since data gathered from Space Station sensors, subsystems, etc., will be transmitted via data busses and processed in computers in order to format and reduce it. These facility requirements are summarized in Table 4.4-5. As seen, there are two sources for facility data. These are the ground and Space Station communications link and the station subsystems health and status data. The first source includes the personal communications of the crew for which three television channels have been allocated. These sources of data will output average raw data rate (including duty cycle) which, when added, yields approximately 100.5 Mbps. This is a continuous data rate which yields in one 92-minute orbit approximately 5.55 by 10^{11} bits. With appropriate assumptions for reduction and compression, this number is reduced to 3.4 by 10^{10} bits per orbit which translates to an equivalent continuous data rate of approximately 6.14 Mbps for downlink. Because of the architecture of the IMS, these facility requirements are the same for the initial and growth stations.

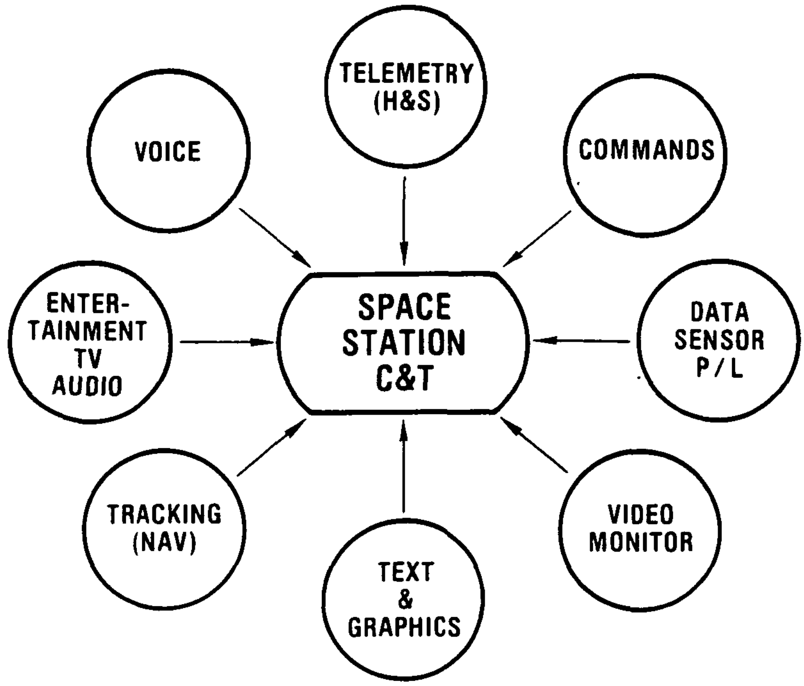


Figure 4.4-2. Communication and Tracking System Requirements

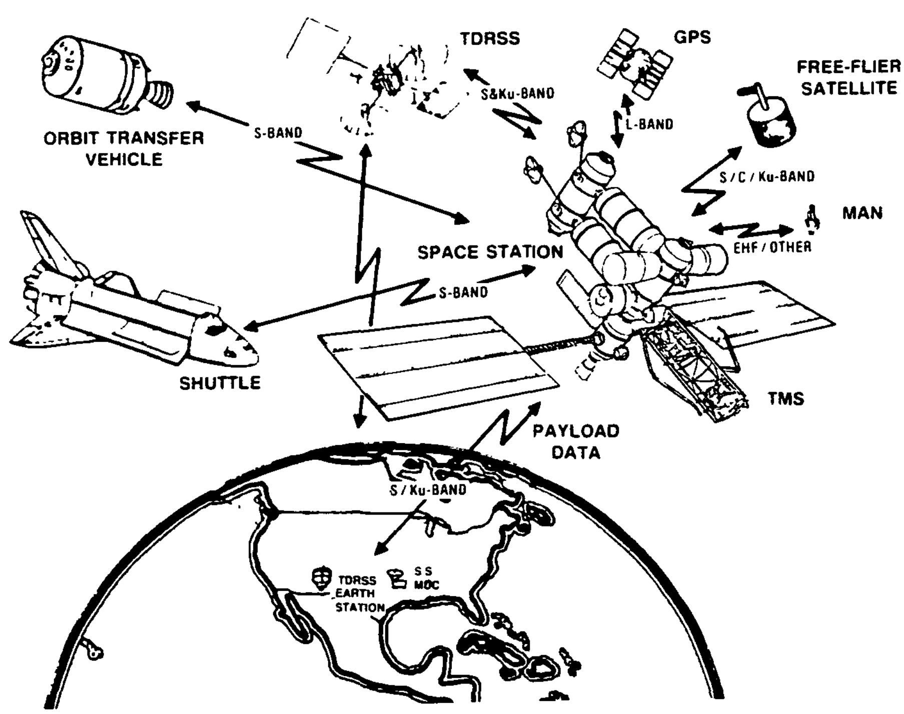


Figure 4.4-3. Space Station Potential Communication Links and Tracking Objects

Table 4.4-5. Baseline Space Station Facility Data Reduction Rates

DATA SOURCE	RAW DATA RATE (MBPS)	RAW BITS * PER ORBIT (MBITS)	DATA REDUCTION RATIO	PROCESSED BITS (MBITS)	DOWN LINK DATA RATE (MBPS)	REMARKS
● CREW TO GND COMM INCL PERSONNELL COM						
— TELEPHONE	0.40	2,210	10:1	221	0.04	10 LINKS (2-WAY)
— HI-RES VIDEO	66.00	364,320	16.5:1	22,080	4.00	1 LINK (2-WAY)
— SLOW SCAN VIDEO	16.50	91,080	16.5:1	5,520	1.00	2 LINKS (2-WAY)
— FASCIMILE	0.06	331	—	331	0.06	2 CHANNELS (2-WAY)
● STATION SUBSYSTEMS HEALTH & STATUS	0.04	221	—	221	0.04	TOTAL FOR ALL SUBSYSTEMS
TOTAL	82.96	458,162	16.1.1	28,373	5.14	

*BASED ON 92 MIN ORBIT (5520 SEC)

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4.5 INTEGRATED TIME-PHASED SYSTEM REQUIREMENTS

The integrated time-phased system requirements that incorporate the user mission payload requirements, and the station facility requirements are summarized in this section. As discussed in the station facility requirements section of this report, there are no significant facility requirements for station storage interfaces and propellant storage. Also, the station pointing and stability requirements represent an environment that the user mission payloads must be worked within. Therefore, the data presented herein represent total system requirements for the areas of crew hours, power, and data processing.

CREW HOURS REQUIREMENTS

The total mission and facility requirements for Space Station crew hours is shown in Figure 4.5-1 for the medium mission model. These data are time-phased annually and by the same user mission areas as shown for the user mission payload requirements in the crew hours requirements section with the facility requirements added. As shown, for the medium mission model, all requirements for crew hours fit within the selected baseline architecture of a four crew member initial station evolving to an eight crew member growth during 1993. The transition from the initial station to the growth station takes place in 1993 with the IOC of the growth station occurring at the start of model year 1994.

POWER REQUIREMENTS

The total mission and facility requirements for Space Station-generated electrical power are given in Figure 4.5-2 for the medium mission model. These data are integrated in the same format as that shown for the station crew hours requirements. The medium model indicates that total mission and facility power requirements fit within the average system sizing parameters of 23.5 kW for the initial station and 50 kW for the growth station. As such, these are the power levels that the solar array systems of each of the two evolutionary station increments must deliver at the bus at end of life.

DATA PROCESSING REQUIREMENTS

The total mission and facility requirements for Space Station data traffic, processing, and communication are illustrated in Figure 4.5-3 for the medium mission model. These data are time-phased annually and by the same user mission areas as shown for the user mission payload requirements in the data processing requirements section with the facility requirements added. The medium model data sums to a total system sizing that can handle 743 Gbits per orbit for the station. With an overall architectural baseline reduction and compression ratio of 4.6:1, these numbers translate into equivalent continuous data rates of approximately 52 Mbps for downlink. These data may all be transmitted to the ground during each orbit in 12 minutes for the station using a 300 Mbps transmission rate. This rate is compatible with TDRS transmission capability.

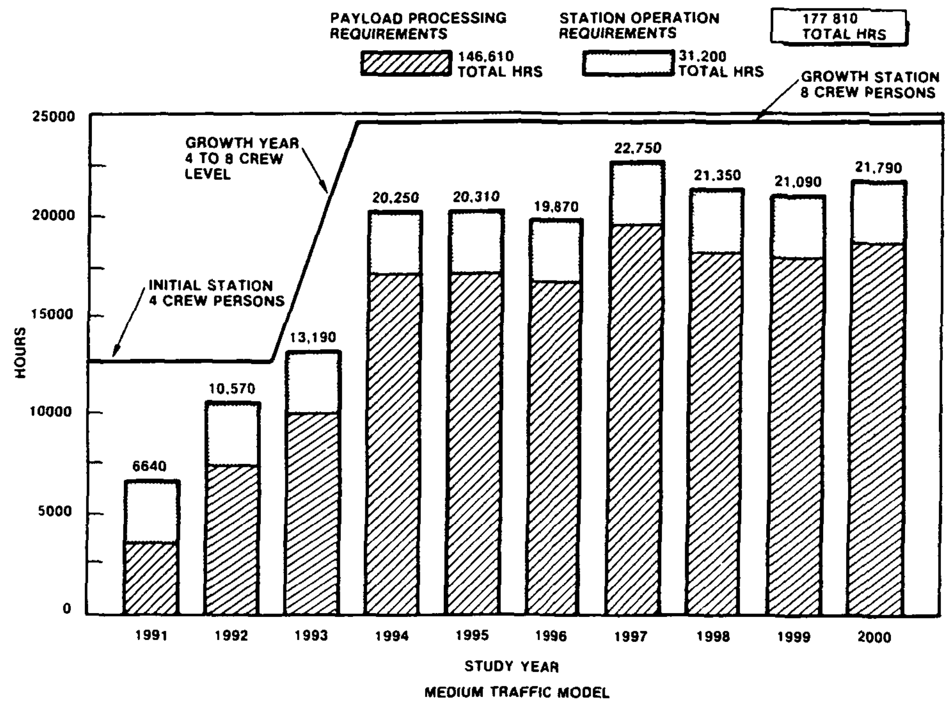

Figure 4.5-1. Integrated Crew Hours Requirements

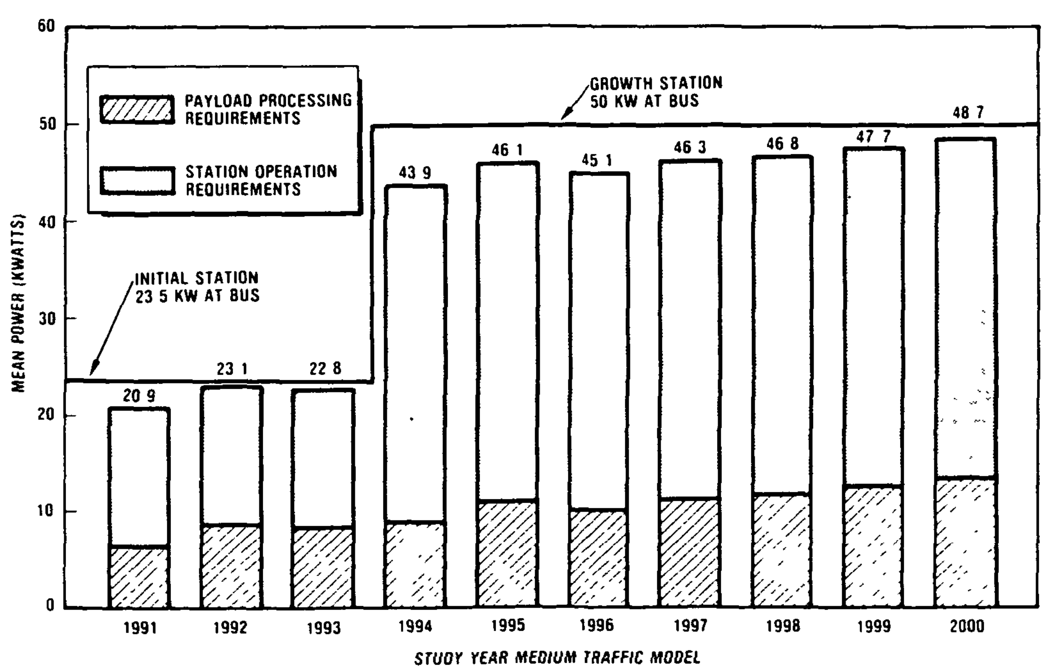

Figure 4.5-2. Integrated Power Requirements

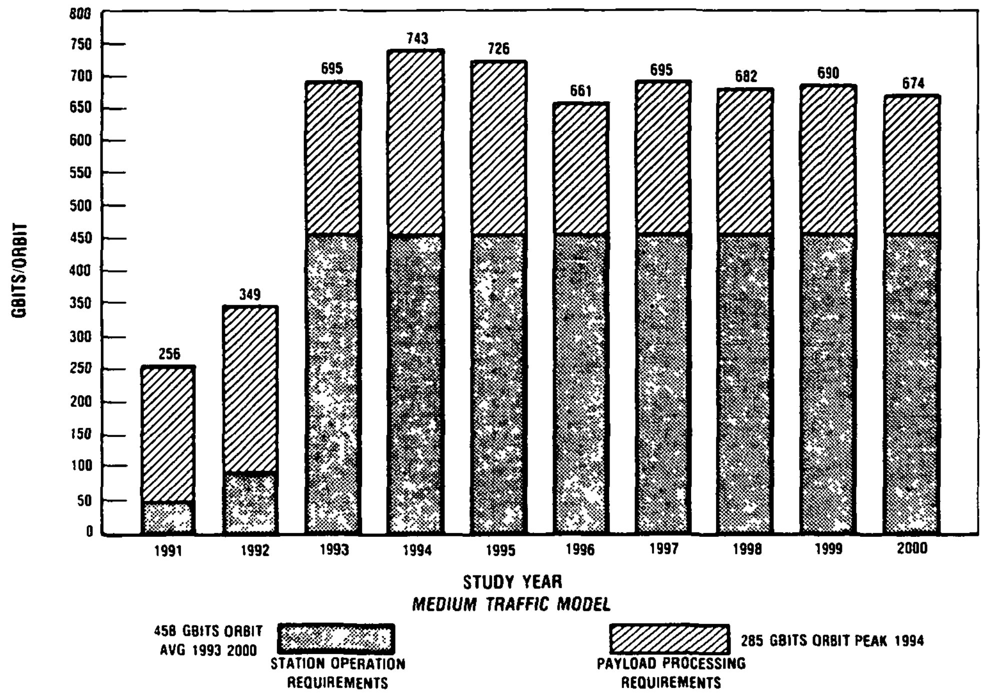

Figure 4.5-3. Integrated Data Requirements

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5.0 CONCLUSIONS AND RECOMMENDATIONS

In summary, the main conclusions and recommendations drawn from this portion of the study are summarized below.

- A representative mission model has been produced
- Incorporates strong user influences
- Validated by user concurrence and economic viability
- Reflects maximum practical use of Space Station
- Commercial user area is the center of greatest uncertainty
- Recommendations for continued model development include:
  - Analyses to reduce commercial user area uncertainties
    - Station user charge policies and sensitivities
    - Government/Industry technology/operations transfer scenarios
  - Analyses to clarify accommodation mode impacts on the mission model
    - Key accommodation mode drivers

      OTV, Commercial?
      System Z and astronomy platform, commonality?
      Commercial space processing, dedicated station?
      Life sciences, scope in the tunnel module?
  - Analyses to better define down cargo and its related requirements

Briefly, Rockwell believes that Scenario 6 is a representative mission model, not necessarily on a mission-by-mission basis, but as an aggregate total. It is affordable within projected budgets and appears to be within expected Shuttle fleet utilization rates. The model reflects the desires and needs of the user community in terms of program area objectives, the kinds of missions desired, and their relative priorities. These were the results of iterative contacts with key representatives and planners within each user area. Within the advanced systems context, the model is validated, not with hard line signatures of commitment (which are impossible for as far out as the year 2000), but by general user concurrence via interface contacts and by economic viability analyses involving return on investment for commercial ventures and budgetary projections for government programs.

The model reflects the maximum practical use of the Space Station (at 28.5 degrees inclination) as iterated with the users. It has been presumed that user charge policies will be developed which will be fair, encourage user acceptance, and lead to full exploitation of station-based services. Feasibility analyses and trades were conducted to define the most useful ways station services could be applied to individual user needs and to establish practical levels of utilization.

Thus, the Scenario 6 mission model represents a solid base for the generation of time-phased requirements.

While the Scenario 6 mission model represents the best thinking and structure currently attainable, three main challenges stand out for early future attention. They involve (1) focusing on the area of greatest uncertainties in the model (the commercial sector), (2) further exploration and definition of key accommodation mode drivers which can affect the mission model, and (3) more rigorous definition of down cargo requirements. It goes almost without saying that mission model development is of necessity an on-going activity. New technologies foster new ideas for both new missions and new ways of doing old missions. Continued developments in support systems and functions offer performance improvements which can push previously unfeasible missions across the threshold of practicality to become viable endeavors. In addition to these routine on-going model development efforts, the above three areas of focus are identified for early attention.

As might be expected, the commercial user area, which comprises four major subgroups, is the mission area of greatest uncertainty. The infrastructure for widespread commercialization of space has not yet emerged nor have the mechanisms for separating private and government functions been established. Thus, further work is required to develop and test competing scenarios to determine under what conditions and with what timing and schedule, major commercial exploitation of space would likely occur.

In the current mission model, the commercial sector contains the following user categories: resource observations, communication services, space processing, and space operations (not specified as commercial in our model). The main factors affecting the uncertainties in each category are discussed.

The resource observations category does not represent a large fraction of the mission model but suffers from complicated government-industry interfaces. This causes large uncertainties in the number of missions. There will probably always be some missions in this category, by NASA, if commercialization is delayed. However, the key to real growth is the emergence of a viable commercial enterprise where private industry has adequate control over the supporting launch and technology resources to assure continuation of services.

The commercial communications industry has utilized satellites for data relay and transmission for over 20 years and represents the only significant commercial exploitation of space thus far. The main area of uncertainty in the commercial communications mission model relates to how many users will select the Shuttle/Space Station/OTV for delivery to GEO over competing launch

systems. Analysis of this issue is centered in user charge policies which are, in turn, affected by the operating efficiencies and costs of the systems and facilities used. Particularly, sensitivities of station user charge policies should be further investigated regarding their interrelationship with other user areas to assure balanced motivation for the use of station services among all user areas.

The real uncertainty in the space processing category is the timing of its emergence to recognized industry status. The payoff potential for space processing is enormous. There are a vast number of potential products (many with extraordinary value) but the risks are high in terms of both technical feasibility and the possibility of alternate ground processes being developed. However, within the current state of knowledge, it appears most certain that space processing, with its profit potential and human benefits potential for breakthroughs in the medical and biological sciences, will become a flourishing industry. The question is--when? This uncertainty leads to large variations in the amount of space processing activity which could appear in the mission model. Perhaps this area is the mission model area with the largest uncertainty and warrants continued attention for careful development.

To help narrow the range of uncertainty in the commercial sector of the mission model, attention must be focused on station user charge policies and user/traffic sensitivities to these policies. Of equal or possible greater importance is the issue of long-range government commitments to provide industry assurance of a continued technology base as well as continued launch and other basic support services. Ways must be explored and criteria developed for the transition of government-developed technologies and operational systems and techniques to private industry for full exploitation. Private investors must be assured of on-going support before they will risk funds on a scale needed to create a new industry such as space processing. As part of this effort, fair ways to implement the transition from government to private industry must be developed which do not concentrate the opportunities for profit among a few favored members.

The start of the iterative process leading to answers for the above issues was initiated with the current Space Station study. Users were contacted, ideas for commercialization explored, and gross concepts defined. The next step is to focus on the user charge policies and sensitivities combined with technology and operations transfer scenarios to determine the combination of factors which would create an investment environment conducive to high levels of industry involvement.

The second major problem area which could affect the mission model and which deserves continued near-term study is the key interactions between mission model and the accommodation models employed. The main accommodation mode drivers are somewhat interrelated with the uncertainty issues above. These are highlighted in the following paragraphs.

OTV, commercial or not? The answer to this question could affect the timing of OTV availability and hence, the amount of traffic captured by the Space Station. Further, it could affect the amount of government funding available for other STS and science and technology developments.

System Z and the astronomy platform--what hardware commonality should exist between these systems and what further commonality might be appropriate between these systems and the Space Station? These questions require further analysis of sensor requirements, budgets, configuration concepts and costs, and would likely affect the timing of their introduction into the mission model.

Commercial space processing--dedicated station a possibility? Economic viability analyses have shown a payoff potential which could justify a dedicated Space Station for materials processing. The impact of this possibility on the Space Station design and on separate station operations for other user areas requires further study.

Life sciences--should it be integrated into the tunnel module? The timing of the tunnel module in the station incremental growth pattern matches the need for expanded on-board medical operations. However, the questions of who pays (Space Station or life sciences) and can the needs for careful isolation of lab environments from station environments be incorporated in practical internal module arrangements require additional study.

Down cargo definition is a third issue requiring further study. The Space Station "empty" logistics module, space processing product packages, retrieved Science and Applications and Technology Development payloads, and OTV's and TMS's for refurbishment are examples of down cargo elements. The weight of down cargo affects the Shuttle delivery performance (sufficient fuel must be carried to deorbit the down cargo). Further, the provisions to return a down cargo element must be carried to the station and properly accounted for in the up-cargo manifests. Most important, however, is the determination of the resources and provisions required for handling and loading the down cargo into the orbiter, the time and specialized equipment it takes and their subsequent impacts on fleet utilization parameters, and what kind of user charge policy should be applied. Thus, down cargo definition must be included to make the mission model complete.

Further efforts in the above problem areas recommended for further study will narrow the range of uncertainty in the mission model and will provide needed understanding of key accommodation mode interactions with the mission model.

The integrated systems requirements definition and analysis shows that, for the early years of projected Space Station operations (1991 through 2000), the nominal model needs for space support systems can be satisfied by the recommended ESTS program architecture. The level of resource requirements are such that the initial station architecture is quickly saturated creating the demand for the transition to the growth station. Also, the interrelationship of the requirements to the total space support system architecture and mission accommodation modes are clearly demonstrated. This architecture includes OTV

operations, TMS operations, satellite servicing, and attached or integral mission operations. The principal issue is providing for growth. As the mission model definition continues, the areas that are expected to contribute significantly to the growth in requirements for space-based resources are the commercial operation and national security missions. As indicated by the high model data, these areas could drive the demand for either a larger station or more units of either the initial or growth stations. Possible locations for additional stations are orbit inclinations other than the 28.5 degrees recommended for the first station.

The requirements data presented in this report are based on an annual analysis for time-phasing. This analysis clearly points to the key issue needed for further study. This issue is taking the time-phasing the next step where the user mission payloads are scheduled in detail during each model year. This will enable these user mission scenarios and timelines to be identified in more depth. Therefore, the scheduling of resources, identification of peak loads (as opposed annual average loads) and the establishment of credible resource plans and schedules can be accomplished. In certain areas, this scheduling can be based on daily events. In addition, the process of continued definition of resource requirements and the need for space support system services for each of the user mission payloads must be on-going. This is necessary in order to keep the station system requirements development on the realistic and validated path. Also, this definition is required for the establishment of efficient Space Station system and subsystem sizing.